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NOTES ON THE ZEEMAN EFFECT.

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INTRODUCTION.

It has been shown by H. M. Reese[1] that the separation of the external components of the regular Zeeman triplet or quadruplet, as seen perpendicular to the lines of force, does not vary proportionally with the strength of the magnetic field in which the luminous source is placed. This fact was established for the zinc lines 4680.38, 4722.26, and 4810.71, and for the three homologous cadmium lines up to a field of about 26,000 c. g. s. units.

Reese also states, in referring to certain lines in the spectrum of iron, that "in comparing the separation of the lines between 3900 and 4450 it was at once observed that the lines could be broken up into two classes, in each of which the separation of the various lines was of the same magnitude. These two classes are identical with those for which Humphreys found that the shift due to pressure was the same. On these plates the separation is very small in all cases, owing to a weak field, and no accurate measurements were taken of the separation."

[1] ASTROPHYSICAL JOURNAL, 12, 120–135, 1900.

It appeared, then, to the author of the following paper to be a matter of no little interest to extend Reese's investigations on zinc, using higher field strengths, and also to make a more exhaustive investigation of the spectrum of iron, measuring with care the separations, and comparing the values so obtained with the shift for the various lines as given by Humphreys.[1]

The following investigation was made primarily with these two ends in view. From time to time, however, as subjects worthy of attention presented themselves, the scope of the work was broadened. In short, the results obtained deal with the following subjects:

1. The variation of the separation with the strength of the magnetic field for zinc and iron to a field of about 33,000 c.g.s. units.

2. The spectrum of iron, including: (*a*) The relation of the separation to the pressure shift as given by Humphreys; (*b*) a study of the iron lines which are affected by the magnetic field in an anomalous manner; (*c*) the laws governing the separation of the iron lines.

3. The spectra of nickel and cobalt—a search for peculiarities and for a law governing the separation.

4. The Zeeman effect along the lines of force.

5. The extension of Preston's law for the homologous lines of the spectroscopic series, namely, that for these lines the expression $\frac{\Delta\lambda}{\lambda^2 H}$ is a constant for lines whose wave-lengths are given by equal values of n in the formula

$$\lambda^{-1} = A + Bn^{-2} + Cn^{-4},$$

where $\Delta\lambda$ stands for the separation of the outer components of the Zeeman triplet, quadruplet, etc.; λ signifies the wave-length of the line in question; H, the strength of the magnetic field; A, B, and C are constants; and n is an integer, 3, 4, 5. . . . .

These subjects will subsequently be discussed in the order given above.

[1] ASTROPHYSICAL JOURNAL, **6**, 169–232, 1897.

APPARATUS.

The grating employed was that used by Reese: Rowland mounting, concave, radius of curvature thirteen feet three inches, of 15,000 lines to the inch, fitted with the ordinary adjustable slit and camera-box with shutter. The first spectrum was the most brilliant; the third could not be used beyond λ 4600 owing to mechanical interference of the beam and truck at that point. The plates used were Seed's "Gilt Edge" and Cramer's "Isochromatic Fast," and the "Erythro" plates of the International Color Photo Company, all cut to 1¼ by 11½ inches. The light from the luminous source passed through a Nicol prism (or doubly refracting rhomb) when such was necessary, a total reflecting prism of quartz (cut with its optical axis parallel to its edge), a condensing lens of quartz (cut with its optical axis parallel to its principal axis), 2½ inches in diameter and of 21 inches focal length; and thence to the spectrometer slit. The total reflecting prism was necessary owing to the size of the magnet and the shape of the room.

The electromagnet was that employed by Reese in his investigations conducted during the scholastic year 1899–1900. The cores, cylinders of soft iron 78.3 cm. long by 15.1 cm. in diameter, are each fitted with two coils of about 1600 turns each, formed of No. 9 B. & S. cloth-covered copper wire. The pole heads are bored to admit of viewing the luminous source along the lines of force if so desired; and, being movable normally to the axis of the cores, are held in position by bolts sunk in the cores themselves. The pole tips proper, of conical form, have a semi-angle of 15°. As used by Reese in his work perpendicular to the lines of force, these pole tips had screwed into them solid pieces of the same semi-angle. The flat surfaces of these latter had a diameter of 3.2 cm. In the following investigations these small terminal pieces were replaced by a pair whose semi-angle was 45° and whose diameter was but 1.5 cm. The result was about 15 per cent. increase in field strength. The field was very uniform at all sizes of gap used — 3 to 7 mm.; in fact, it varied by an amount about equal to the error of reading of the ballistic

galvanometer used to measure its strength. The two coils on each core were connected in series, the two pairs in parallel. A current of thirty amperes in the main circuit and twelve amperes in the coils gave a field of over 33,000 c.g.s. units for a gap of 3 mm.

The luminous source was a spark between metal terminals, which were ground flat and firmly held in the arms of an adjustable device fitted with two racks and pinions. Thus was furnished an exceedingly efficient means of adjusting the spark gap even during exposure; and, as a result, small terminals could be used and the metal fed in at any desired speed.

Nickel wire of about 1 mm diameter, and small pieces of cobalt soldered with silver solder to brass terminals and then ground flat, were used for the spectra of those metals and furnished no trouble even in strong fields. Iron wire of about 1½ mm diameter, ground flat to less than 1 mm thickness, was used for the iron spectrum. To keep these highly magnetic terminals away from the pole tips, adjustable bracings of asbestos, wood fiber and brass were used; and no difficulty was experienced in feeding in the metals during exposure. Zinc, cadmium and magnesium are handled easily. Mercury was fed from a reservoir of adjustable height through a rubber tube to the lower brass terminal, which was hollow. The upper electrode was of brass. The spectra of calcium and of strontium were obtained as follows: The chlorides of these metals were quickly ground fine in a mortar and put at once in test tubes in a desiccator. Copper wire of about 2½ mm diameter was drilled to the depth of about 2 cm so that merely a shell remained. The salt was then packed tightly in the tubular cavity, the end pinched and the wire pounded flat. The hygroscopic character of these salts is the objectionable feature.

The spark used as luminous source was produced as follows: An alternating current of 133 cycles per second was received at about 110 volts difference of potential. This was passed through an adjustable impedance of closed magnetic circuit and through a transformer whose ratio of transformation was 110 to 8000.

From the secondary of the transformer connections were made to a condenser placed as near as possible to the spark gap. From the condenser short thick wires lead directly to the spark gap. The impedance could be so adjusted that the spark was either brilliant, excessively disruptive and "cool" (if, indeed, it be proper to speak of the temperature of a spark), or less brilliant, more continuous and "hot," approaching—though but to a very slight degree—an arc. The difference of potential at the terminals of the transformer varied from 4 to 28 volts according as the spark gap used was small (about 1 mm) or large (about 7 mm). This gave a potential difference at the terminals of the secondary of from 300 to 2100 volts. The condenser was built of forty glass plates, of 1/8 inch thickness, separated by 36 square inches of brass foil. Thus was obtained a capacity of about 0.014 microfarads.

The adjustable impedance transformer and condenser were kindly loaned by Dr. E. F. Northrup and proved of great service.

Several turns of an air-coil of about 15 cm diameter were often inserted in the discharge circuit for various reasons which will be touched upon later.

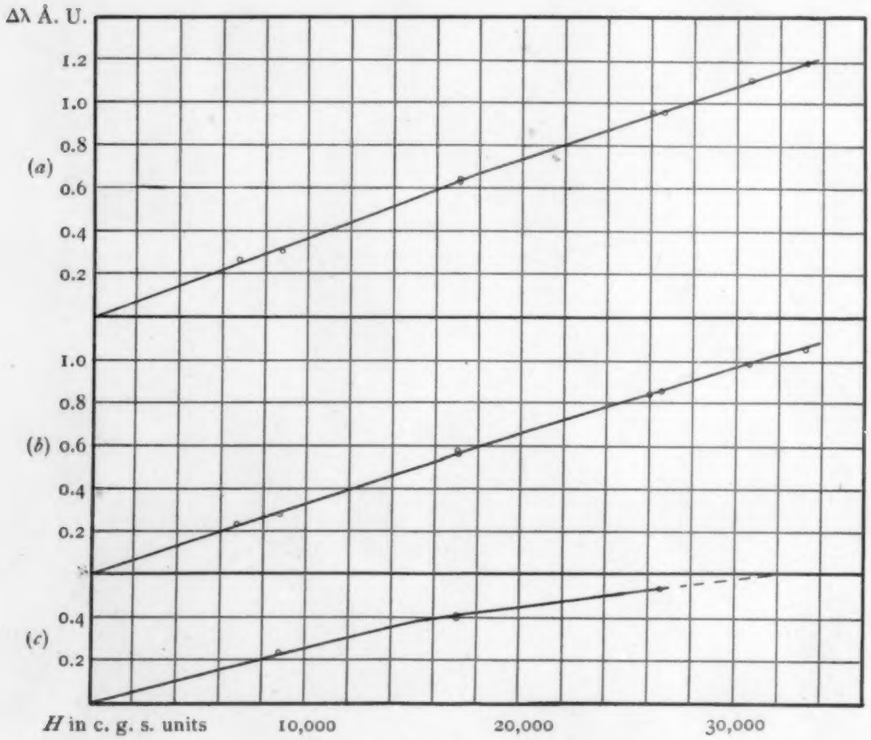
The dividing engine used to measure the separation of the lines was that designed by Professor Rowland and used for the construction of his table of the solar spectrum. The error of the screw is far less than the error of setting on even the sharpest lines.

ACCOUNT OF EXPERIMENTS.

1. *The variation of the separation with the strength of the magnetic field.*—For Zinc: Table 1 gives the distance in Ångström units between the outer components of the sharp triplet zinc λ 4680.38, between the means of the outer components of the sextuplet zinc 4722.26 (see Fig. 1), and between the outer components of the diffuse triplet zinc 4810.71. The values of the separation given represent the measurements on plates taken when the requisite conditions were obtained in two different ways: set I with a small magnetic

FIG. 1

gap and the magnetizing current changed to obtain different strengths of field, set II with the current constant and the width of gap changed. This shows the uniformity of the field and the ease of control of the conditions. The line 4722.26 appears as a



Zinc lines: (*a*) λ 4680.38; (*b*) λ 4722.26; (*c*) λ 4810.71.

FIG. 2. SEPARATION Δλ AS A FUNCTION OF FIELD STRENGTH *H* (TABLE I).

sextuplet only with the strongest fields, otherwise as a quadruplet.

The accompanying curves (Fig. 2) explain themselves. Reese's maximum field was 26,600 c. g. s. units. His results are in general confirmed. The drop in the curve is very marked in the case of 4810.71. The sharp triplet and the quadruplet give a curve which approximates a straight line.

TABLE I.

Zinc. $\Delta\lambda$ as a function of H.[1]

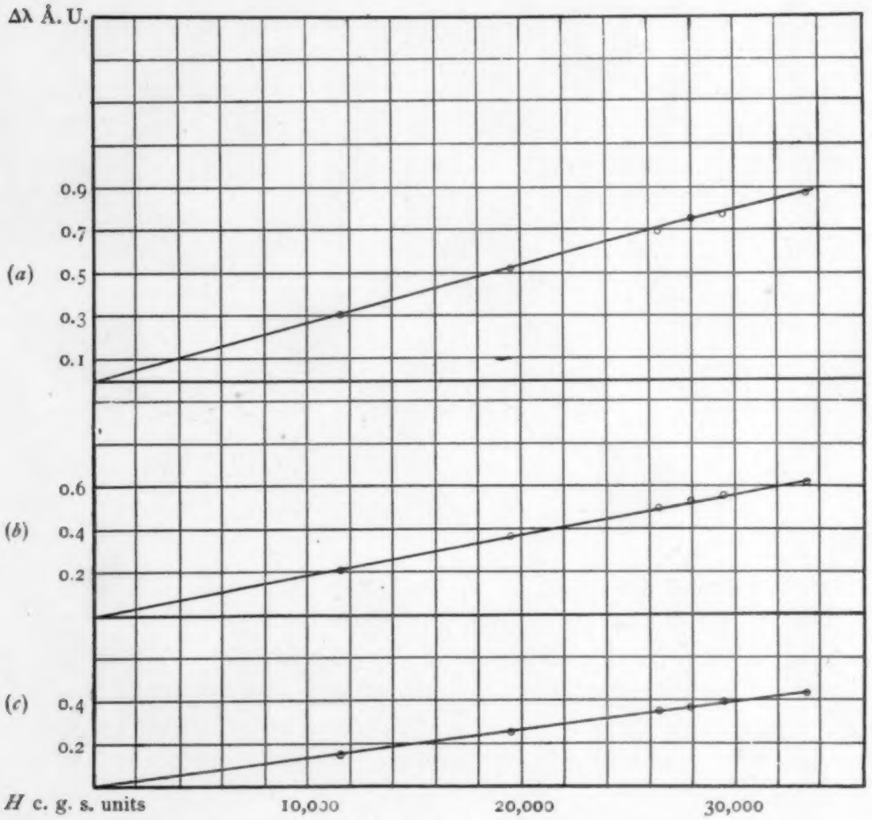
λ	Intensity[2] and character	$\Delta\lambda$ for given values of H			
		SET I			
		8.820	17.110	26.060	30.660
4680.38	10 r	0.313	0.646	0.961	1.106
4722.26	10 r	.278	.578	.852	0.988
4810.71	10 r	.240	.412	....	....
		SET II			
		6.800	17.140	26.630	33.320
4680.38	10 r	0.266	0.630	0.959	1.194
4722.26	10 r	.238	.568	.864	1.060
4810.71	10 r	....	.400	.543	.....

For Iron: Tables II to IV and Figs. 3 to 5 explain themselves. It will be noted that with this metal the drop appears to be less. The three lines, 3737.27, 3920.40, 4033.24, which as a result of the magnetic field appear in the spectrum as sharp triplets, one of small, one of medium, and one of large separation, were chosen at random; as were also the two lines, 3887.18 and 3903.09, which appear as quadruplets, and the two 3834.38 and 4030.89, which appear as somewhat diffuse triplets—in each of these last sets one of larger and one of smaller separation. 3834.38 is not very diffuse, while 4030.89 is quite so, and indeed, is classed as "nebulous" in Exner and Haschek's table.

The curves show that the separation is not proportional to the field strength for strong fields—the curves are not straight lines, but droop; and it is apparent that the division into classes of small and large droop is dependent upon the character of the line and not on the degree of initial separation, whether large or small.

[1] λ and $\Delta\lambda$ in Ångström units. Wave-lengths as given in Kayser and Runge's tables. H in c. g. s. units.

[2] Maximum intensity = 10; r stands for "easily reversed."



Sharp Iron Triplets: (*a*) λ 4033.24; (*b*) λ 3920.40; (*c*) 3737.27.

FIG. 3.—Δλ AS A FUNCTION OF *H* (TABLE II).

The plates which gave these results both in the case of zinc and iron, were taken in the second spectrum; the time of exposure varied from 20 to 120 minutes; and the deviation of the mean in measurement was such that, in general, the values may be considered correct to 0.01 of an Ångström unit in the case of zinc and to 0.007 Å. U. in that of iron.

TABLE II.

Iron. Δλ as a function of *H*. Sharp triplets.[1]

Plate	Field	λ	Intensity (10-max.)	$\Delta\lambda_s$ [2]	Mean $\Delta\lambda_s$	Δλ (Å.U.)
387	11.600	3737.27	8	0.0740		0.160
387	11.600	3920.40	5	.1000		.216
387	11.600	4033.24	1	.1433		.310
386	19.600	3737.27	8	.1203		.260
386	19.600	3920.40	5	.1705		.369
386	19.600	4033.24	1	.2425		.524
359	26.460	3737.27	8	.1665		.360
359	26.460	3920.40	5	.2328		.503
359	26.460	4033.24	1	.3195		.691
345	28.000	3737.27	8	.1715	0.1725	.373
350	28.000	3737.27	5	.1735		
345	28.000	3920.40	1	.2488	.2488	.538
350	28.000	3920.40	8	.2488		
345	28.000	4033.24	5	.3460	.3445	.745
350	28.000	4033.24	1	.3430		
355	29.500	3737.27	8	.1838		.397
355	29.500	3920.40	5	.2595		.561
355	29.500	4033.24	1	.3585		.775
400	33.400	3737.27	8	.2025		.438
400	33.400	3920.40	5	.2890		.625
400	33.400	4033.24	1	.4018		.869

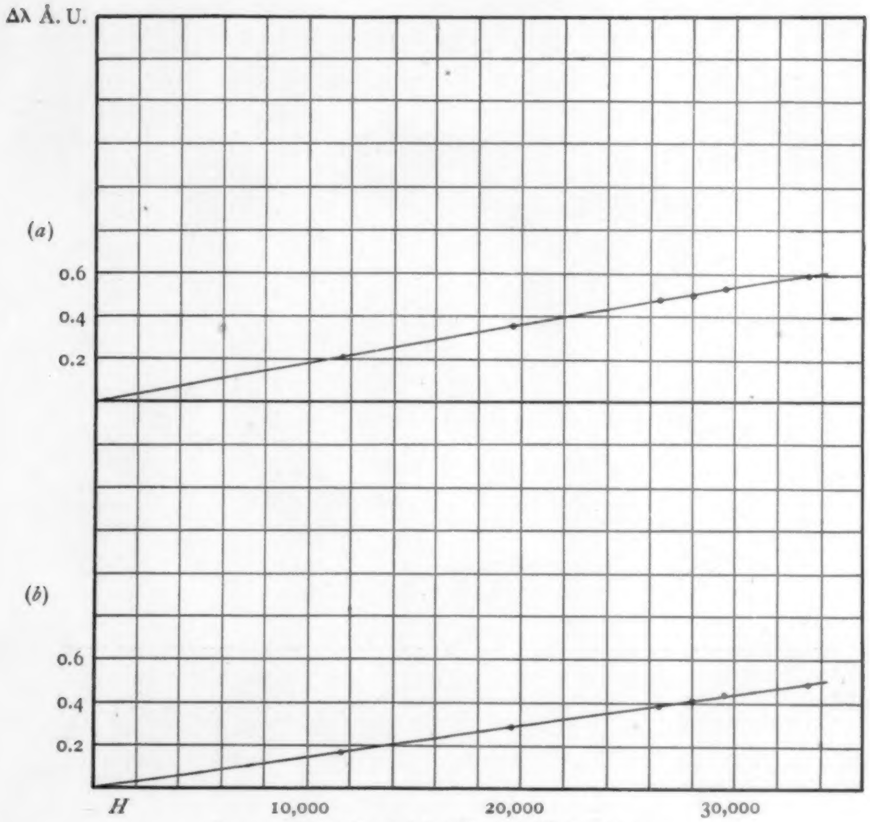
TABLE III.

Iron. Δλ as a function of *H*. Quadruplets.

Plate	Field	λ	Intensity	$\Delta\lambda_s$	Mean $\Delta\lambda_s$	Δλ (Å. U.)
387	11.600	3887.18	5	0.0958		0.207
387	11.600	3903.09	7	.0803		.174
386	19.600	3887.18	5	.1648		.356
386	19.600	3903.09	7	.1333		.288
359	26.460	3887.18	5	.2195		.475
359	26.460	3903.09	7	.1793		.388
345	28.000	3887.18	5	.2310		.499
345	28.000	3903.09	7	.1905	0.1902	.411
350	28.000	3903.09	7	.1900		
355	29.500	3887.18	5	.2468		.533
355	29.500	3903.09	7	.2043		.442
400	33.400	3887.18	5	.2741		.593
400	33.400	3903.09	7	.2258		.488

[1] Nearly all of the iron lines are sharp. With difficulty could diffuse lines be found. 4030.89 is the most diffuse of any and is marked "nebulous" in Exner and Haschek's table. From this table are taken also the wave-lengths and the intensity of the iron lines.

[2] Δλ as measured in screw-turns of dividing engine.



Iron quadruplets: (a) λ 3887.18; (b) λ 3903.09.

FIG. 4.—Δλ AS A FUNCTION OF H (TABLE III).

TABLE IV.

Iron. Δλ as a function of H. Somewhat diffuse triplets.

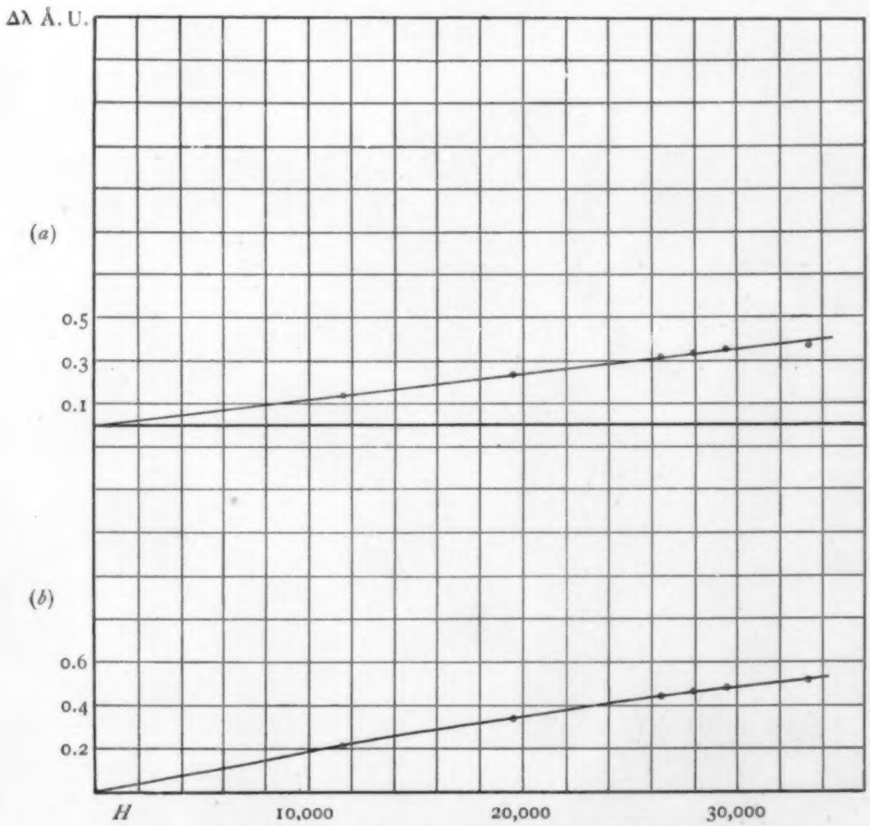
Plate	Field	λ	Intensity and Character	$\Delta\lambda_g$	Mean $\Delta\lambda_g$	Δλ (Å. U.)
387	11.600	3834.38	8	0.0638		0.138
387	11.600	4030.89	2n[1]	.0981		.212
386	19.600	3834.38	8	.1115		.241
386	19.600	4030.89	2n[1]	.1562		.338
359	26.460	3834.38	8	.1495		.323
359	26.460	4030.89	2n[1]	.2035		.440
345	28.000	3834.38	8	.1602		.346
345	28.000	4030.89	2n[1]	.2147	} 0.2145	.464
350	28.000	4030.89	2n[1]	.2144		
355	29.500	3834.38	8	.1658		.358
355	29.500	4030.89	2n[1]	.2223		.487
400	33.400	3834.38	8	.1733		.375
400	33.400	4030.89	2n[1]	.2420		.523

[1] Nebulous.

TABLE Va.

Small Δλ. (0.28 to 0.55 Å. U.) and small ΔP (0. 01 to 0.02 Å. U.)

Spark[1]		Δλ[2]	ΔP[3]	Arc[4]		C[6]
λ	I_s			I_a	λ	
3969.40	8	0.55	0.01	8	3969.34	P s r
97.52[5]	4	.41	.01	6	97.49	B s u
4030.89	2n	.46	.01	6	4030.84	B s r
45.98[5]	10	.47	.02	10	45.90	B s r
63.75[5]	10	.41	.01	10	63.63	B s r
71.92	10	.28	.01	10	71.79	B s r
4118.72[5]	5	.41	.02	10	4118.62	B s u
81.94	7	.52	.02	8	81.85	B s u
99.27[5]	8	.43	.01	10	99.19	B s u
4219.51[5]	6	.46	.01	8	4219.47	B s u
71.93	10	.52	.01	10	71.93	B s r
82.60	6	.54	.01	10	82.58	B s u
4308.06	10	.48	.01	10	4307.96	B s r
25.94[5]	10	.39	.01	10	25.92	B s r
83.71[5]	10	.51	.01	10	83.70	B s r
4404.94[5]	10	.51	.01	10	4404.88	B s r



Somewhat diffuse iron triplets: (*a*) λ 3834.38; (*b*) λ 4030.89.

FIG. 5—.Δλ AS A FUNCTION OF *H* (TABLE IV).

TABLE Vb.

Large Δλ (0.59 to 0.03 Å. U.) and large Δ P (0.05 to 0.12 Å. U.)

Spark[1] λ	Spark[1] I_s	Δλ[2]	ΔP[3]	Arc[4] I_a	Arc[4] λ	C[6]
4187.22	7	0.61	0.07	10	4187.17	P n u
88.00	7	.60	.10	10	87.92	P n u
98.50	6	.59	.08	10	98.42	P n u
4208.73	2	.93	.05	4	4208.71	P n u
22.35[5]	4	.77	.09	8	22.32	P n u
36.09[5]	8	.67	.06	10	36.09	P n u
60.64[5]	10	.68	.10	10	60.64	P n r
99.43	7 r	.63	.10	10	99.42	P n u
.....	..	.71	.12	10	5573.05	P n u
.....	..	.80	.10	10	86.92	B n r

TABLE Vc.

Large Δλ (0.60 to 0.81 Å. U.) and small Δ P (0.01 to 0.02 Å. U.)

Spark[1] λ	Spark[1] I_s	Δλ[2]	ΔP[3]	Arc[4] I_a	Arc[4] λ	C[6]
4005.40[5]	8	0.60	0.01	8	4005.33	P s r
33.24	1	.75	.01	6	33.16	B r & P n r
4132.24	8	.67	.01	10	4132.15	P s r
44.06	7	.60	.01	10	43.96	P n r
4315.26	5	.81	.02	10	4315.21	B s u
76.10	4	.65	.02	8	76.04	B s u

TABLE Vd.

Small Δλ (0.41 to 0.48 Å. U.) and large Δ P (0.08 to 0.09 Å. U.)

Spark[1] λ	Spark[1] I_s	Δλ[2]	ΔP[3]	Arc[4] I_a	Arc[4] λ	C[6]
4233.74[5]	6	0.41	0.08	10	4233.76	P n u
....	..	.48	.09	10	5569.67	B s u

NOTES ON TABLES V a, b, c, d:

1. Exner and Haschek — Rowland's scale. Intensity and character that of original line.

2. Δλ, in Ångström units, taken, with three exceptions, from Table VII.

3. Δ P = approximate pressure shift in Å. U. as measured by me on plates taken by Dr. Huff at pressure of about 9 atmospheres.

4. Kayser and Runge; wave-lengths Rowland's scale. Intensity and character that of original line.

5. Lines which appear in Humphrey's table, page 200. ASTROPHYSICAL JOURNAL, **6**, October 1897, as corrected by Ames and others (see ASTROPHYSICAL JOURNAL, **8**, 50).

6. Character of original line and that under pressure as apparent on Dr. Huff's plates.

B n r	signifies :	Both original line and that under pressure non-symmetrical and reversed.
B s r	"	Both original line and that under pressure symmetrical and reversed.
B s u	"	Both original line and that under pressure symmetrical and unreversed.
B r	"	Both original line and that under pressure reversed.
P s r	"	Line under pressure symmetrical and reversed.
P n u	"	Line under pressure non-symmetrical and unreversed but very much broadened. Original line symmetrical and unreversed.
P n r	"	Line under pressure non-symmetrical and reversed.

2. *The spectrum of iron.*

As an introduction it may be said that nearly all the results given under this section were obtained from plates taken in the second spectrum. The time of exposure varied from 30 to 135 minutes; and the values of the separation given are correct to 0.008 Å. U., generally speaking.

(*a*) The relation of the Zeeman effect to the pressure shift.

As, upon a preliminary survey, Reese's statement before mentioned was not confirmed by measurements of the separation made on my plates, and, as Humphrey's table had been shown incorrect in several particulars (see Ames, Earhart, and Reese, ASTROPHYSICAL JOURNAL, **8**, 50, 1898), it seemed best to go over Humphrey's work with care. This was rendered possible by the kindness of Dr. Huff, who happened to be working upon the pressure shift. He furnished me with three excellent plates taken (for a pressure of about 9 atmospheres) in the second spectrum of the 20-foot Rowland grating used by Humphreys. Tables V, a, b, c, d contain the results. It is apparent that Reese's statement, that the lines could be broken up into two classes in each of which the separation, $\Delta\lambda$, was of the same magnitude, these two classes being identical with those for which Humphreys found that the shift due to pressure, ΔP, was the

same, is not verified. The statement was true of the lines on his plates—a mere coincidence. As appears from the tables given, the majority of lines obey Reese's law, 26 against 8; or 24 per cent. are exceptions, 76 per cent. follow the rule.

The conclusions which may be drawn from this study are that in general the lines for which $\Delta\lambda$ is large (1) show a large pressure shift and (2) as a result of pressure are broadened

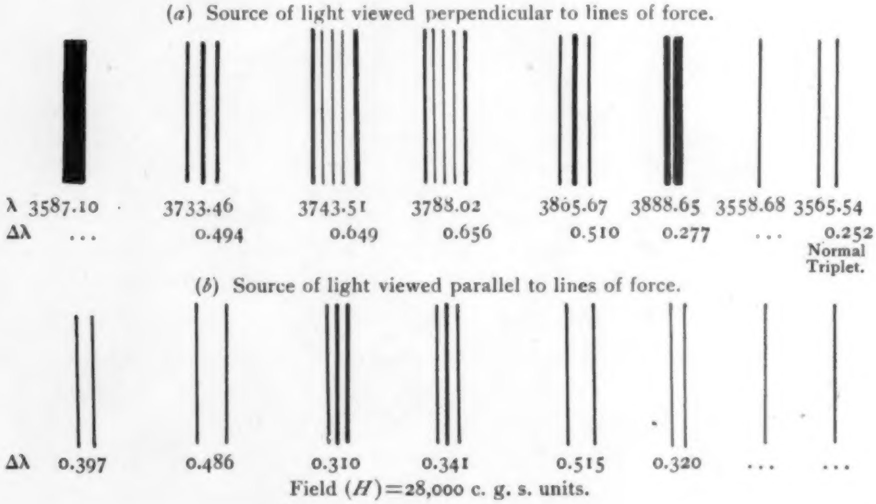


FIG. 6.—PECULIAR IRON LINES.

excessively and rendered unsymmetrical—whether reversed or unreversed—being sharper on the violet side and shaded toward the red. Again, in general, the lines which show a small $\Delta\lambda$ are, under pressure, symmetrical whether reversed or not. The exceptions are clear and unmistakable.

(*b*) A study of the anomalous iron lines.

Becquerel and Deslandres[1] have made quite an exhaustive study of those iron lines which do not appear as triplets or quadruplets of the ordinary type. I have studied these lines with care and made some measurements upon them. The conclusions reached agree with those of Becquerel and Deslandres in all cases save one—that of line 3888.63.

[1] *Comptes Rendus*, **127**, 18–24, 1898.

The types appearing on my plates are most easily explained graphically, as given in Fig. 6. Tables VI a and VI b contain the measurements taken.

Vertical vibrations or those perpendicular to the lines of force:

3587.10 appears on all my plates as an indefinable band.

3733.46 is a sharp triplet of inner component twice as strong as the two outer.

3743.51 is a quintuplet. Of the two outermost components the red is the more intense. Between the two lies a band completely filling the gap, and this band is, on several plates, clearly marked by three very fine faint lines which appear to be separated by distances about equal to those components which are polarized in the other plane (see below). These three fine lines appear of equal intensity. The red component of the strong doublet appears the more intense irrespective of the field — a fact which proves that the asymmetry is not due to the interference of another line. Note the accompanying component's asymmetry.

3788.02 resembles 3743.51, but the two strong components are of equal intensity.

3865.67 resembles 3733.46 exactly.

3888.65 appears distinctly on several plates as two diffuse lines, the red being a trifle more intense. Becquerel and Deslandres describe this line as a characterless band instead of two diffuse lines.

TABLE VIa.[1]

Anomalous lines in the iron spectrum.

$\Delta\lambda$, or the separation of the components whose vibrations are perpendicular to the lines of force. $H = 28{,}000$.

Plate	λ	Intensity	$\Delta\lambda_s$	Mean $\Delta\lambda_s$	$\Delta\lambda$ (Å. U.)
345	3733.46	6	0.2290	0.2284	0.494
350	33.46	6	.2278		
345	43.51	7	.2965	.3001	.649
350	43.51	7	.3038		
345	88.02	5	.3032	......	.656
345	3865.67	6	.2325	.2360	.510
350	65.67	6	.2395		
350	88.65	6	.1279	......	.277

[1] Notation used similar to that of Table II.

TABLE VIb[1].

Anomalous lines in the iron spectrum.

$\Delta\lambda'$, or the separation of the components whose vibrations are parallel to the lines of force. $H = 26{,}000$.

Plate	λ	Intensity	$\Delta\lambda'_s$	Mean $\Delta\lambda'_s$	$\Delta\lambda'$ (Å. U.)
351	3587.10	5	0.1838	......	0.397
345	3733.46	6	.2245	......	.486
345	43.51	7	.1403	......	.310
351	88.02	5	.1598	0.1578	.341
345	88.02	5	.1558		
351	3865.67	6	.2373	.2382	.515
345	65.67	6	.2390		
351	88.65	6	.1490	.1487	.320
345	88.65	6	.1483		

Horizontal vibrations or those parallel to the lines of force: 3587.10 is a doublet.

3733.46 is a doublet whose components are separated (to within the error of observation) by a distance equal to the separation, $\Delta\lambda$, of the vibrations perpendicular to lines of force.

3743.51 is asymmetrical as noted above, the two red components being of equal intensity and both stronger than the violet component. Note that $\Delta\lambda =$ approximately $2\ \Delta\lambda'$.

3788.02 is symmetrical but otherwise similar to 3743.51. Here again note that $\Delta\lambda =$ approximately $2\ \Delta\lambda'$.

3863.67 is exactly similar to 3733.46.

3888.65 is a sharp doublet of $\Delta\lambda' > \Delta\lambda$. Therefore 3888.65 as a whole is of the form of an inverse quadruplet, $\Delta\lambda$ being unusually diffuse.

With regard to asymmetry, Zeeman[2] has, in weak fields verified to some exte nt Voigt's[3] theory. The only one of these lines which is given in Zeeman's list is 3733.46. This in weak fields is said to show reversed asymmetry—the violet component is nearer the central component than is the red. Line 3743.51 is not noted by Zeeman as unsymmetrical in the intensity of its components.

[1] Limit of error in $\Delta\lambda$ and $\Delta\lambda'$ about 0.01 Å. U.

[2] *Proceedings Royal Acad. Sci. Amsterdam*, **2**, 298–301, 1900.

[3] *Ann. der Physik*, **1**, 376–388, February 1900.

All these variations are interesting, but at present mean little. They merely show that the mathematical and mechanical theories which have been advanced in explanation are too simple —the complexity of separation and polarization has not yet been accounted for.[1]

(*c*) The laws governing the separation of the iron lines. Becquerel and Deslandres have made the following statements:

That the complexity of phenomena present in the iron spectrum renders it difficult to form a law governing the separation of the different lines, but that the following general chracteristics are apparent:

1. The separation in the ultra-violet is notably less than that in the blue, and the phenomenon appears a function of the wave-length, which increases with that variable.

2. If a restricted region — that very rich in lines — be examined it appears that many anomalous separations and separations of very different magnitudes lie in the immediate neighborhood of the lines which are insensible to magnetic influence. If an effort is made to classify the separations as a function of the wave-length of the corresponding lines it is evident that "for the most part" they can be put in different classes such that for lines of neighboring wave-length the separation is proportional to the numbers 1, 2, 3, 4. . . . . and that in one and the same class the separation varies as the square of the wave length.

3. Again, for the lines which are divided into fine components or inversely polarized, $\Delta\lambda$ and $\Delta\lambda'$ are for the same line, "exactly proportional to 1, 2, 3, 4 . . . ."

4. The distribution of the separation in the spectrum as a function of the wave-length shows in general a sort of periodicity.

The first statement is approximately true. The meaning of the second is not at all clear. No numerical data are given in their paper. The third statement is true for 3733.46, 3865.67, 3743.51 and 3788.02. The fourth is not apparent from the measurements made on my plates. To settle this last point

[1] See article by Lorentz, *Proceedings Royal Acad. Sci.*, 1, 340–359, 1899.

TABLE VII.

Plates 345 and 346. $H = 28,000$.
Iron spectrum. Lines appearing as triplets.

λ[1]	Intensity	$\Delta\lambda$	$\frac{\Delta\lambda}{\lambda^2} \times 10^{10}$	λ[1]	Intensity	$\Delta\lambda$	$\frac{\Delta\lambda}{\lambda^2} \times 10^{10}$
3565.54	8 r	0.252	198	28.09	7	0.533	345
70.18	8	.326	256	30.43	6	.532	345
81.36	10 r	.359	279	69.40	8	.545	345
3618.92	10	.245	187	97.52	4	.408	255
31.64	10	.284	216	4005.40	8	.594	370
48.00	9	.291	219	30.89	2 n	.464	286
87.55	6	.471	348	33.24	1	.748	460
3709.40	6	.473	344	45.98	10	.473	289
20.10	8	.393	284	63.75	10	.411	249
27.78	6	.478	344	71.92	10	.277	167
35.01	10	.453	325	4118.72	5	.406	240
37.27	8	.371	266	32.24	8	.674	394
48.41	7	.256	182	4144.06	7	.603	351
49.64	10	.432	307	81.94	7	.521	298
58.39	8	.403	286	87.22	7	.611	348
63.91	7	.328	231	88.00	7	.599	342
65.70	5	.339	239	98.50	6	.589	334
95.15	6	.508	353	99.27	8	.426	242
98.68	6	.491	340	4208.73	2	.925	522
99.70	7	.487	338	19.51	6	.458	257
3813.12	5	.312	214	22.35	4	.768	431
15.99	9	.382	262	27.60	7	.483	270
3820.57	9	.425	291	33.74	6	.412	230
24.58	7	.504	345	36.09	8	.673	375
26.04	9	.386	264	60.64	10	.676	372
27.98	9	.346	236	71.93	10	.524	287
34.38	8	.347	236	82.60	6	.544	297
40.61	8	.261	177	99.43	7 r	.632	342
41.21	8	.273	185	4308.06	10	.480	259
56.51	8	.501	337	15.26	5	.813	437
60.07	9	.527	354	25.94	10	.390	209
86.41	8	.523	347	76.10	4	.652	333
95.78	5	.516	340	83.71	10	.514	267
99.84	6	.520	342	4404.94	10	.512	258
3920.40	5	.532	347	15.29	8	.540	277
23.05	6	.531	345	4528.80	6	.569	277

three plots were made by me from values of $\Delta\lambda$ for lines 3565.54 to 4528.80 as given in Table VII. As abscissæ λ, and as ordinates, $\Delta\lambda$, $\frac{\Delta\lambda}{\lambda}$, $\frac{\Delta\lambda}{\lambda^2}$, respectively, were plotted. No periodic variation of any of these three quantities with λ was shown.

[1] λ and $\Delta\lambda$ expressed in Ångström units. Wave-lengths and intensities as given by Exner and Haschek. The character of the lines is sharp. r means "easily reversed."

The subject does not merit discussion. The only method which at the present time seems justifiable and productive of results is that which deals with homologous lines in the spectra of different elements or lines of the same series in the spectra of any one element.

The following Tables VII and VIII explain themselves. One thing is certain. Becquerel and Deslandres are not justified in attempting to make a classification or formulate a law from data obtained with such a high field as used by them—namely, that of 35,000 c. g. s. units. From the curves of Figs. 3 to 5 it is apparent that $\Delta\lambda$ does not increase proportionally with the field for all lines. The difference at 28,000 is considerable; at 35,000 it would be much greater.

TABLE VIII

Plates 345 and 346. $H = 28,000$.
Iron Spectrum. Lines appearing as quadruplets.[1]

λ	Intensity	$\Delta\lambda$	$\Delta\lambda'$	$\frac{\Delta\lambda}{\Delta\lambda'}$	$\frac{\Delta\lambda}{\lambda^2}\times 10^{10}$	$\frac{\Delta\lambda'}{\lambda^2}\times 10^{10}$
3680.06	5	0.440	.....	...	325	...
3705.73	6	.435	0.181	2.4	317	132
22.73	6	.424	.279	1.5	307	200
3872.65	6	.424	.315	1.3	283	210
87.18	5	.499	.150	3.3	331	99
3903.09	7	.412	.214	1.9	270	141
4202.20	9	.494	.218	2.3	280	124
94.32	6	.511	.238	2.1	277	129

Lines which are apparently unaffected:

λ	3558.68	3609.02	3767.32	3850.15
Intensity	6	9	7	6

3. *The spectra of nickel and cobalt.*—A search for peculiarities and for a possible law connecting the separation.

Most of the work done with nickel and cobalt was confined to the first spectrum, owing to lack of brilliancy in the spectra

[1] Separation of inner components given as $\Delta\lambda'$.

of these metals. This reduced very much the chances of the discovery of any peculiar lines, if such indeed exist. No law governing the separation is evident in either of these metals, nor is any periodic variation of $\Delta\lambda$, $\frac{\Delta\lambda}{\lambda}$, or $\frac{\Delta\lambda}{\lambda^2}$ with λ apparent.

TABLE IXa.[1]

Plates 314, 319, 328, and 332.

Nickel. Lines appearing as triplets.

Plate	Spectrum	Field	λ	Intensity	$\Delta\lambda_s$	$\Delta\lambda_m$ $H=32,800$	$\Delta\lambda$ (Å. U.) $H=32,800$	$\frac{\Delta\lambda}{\lambda^2}\times 10^{10}$
314	1	32,740	3391.21	6	0.0842	0.0844	0.365	318
314	1	32,740	93.10	7	.0920	.0921	.399	346
328	1	32,800	93.10		.0920			
328	1	32,800	3414.90	8	.0938	.0938	.406	348
314	1	32,740	33.71	7	.0920	.0922	.399	339
314	1	32,740	46.34	8	.0807	.0809	.350	295
314	1	32,740	52.98	7	.0920	.0922	.399	335
319	1	32,500	61.78	8 n r	.0875			
314	1	32,740	61.78		.0945	.0917	.397	330
328	1	32,800	61.78		.0920			
314	1	32,740	72.68	7 n r	.1112	.1114	.482	401
328	1	32,800	93.10	9 n r	.0720	.0720	.311	255
314	1	32,740	3501.00	6	.0850	.0852	.368	301
314	1	32,740	14.06	5	.0930	.0932	.403	327
314	1	32,740	15.17	9 n r	.0777			
328	1	32,800	15.17		.0715	.0785	.339	275
332	2	33,400	15.17		.1677			
328	1	32,800	24.65	10 n r	.0992	.0947	.410	330
332	2	33,400	24.65		.1885			
328	1	32,800	66.50	9 n r	.0725	.0725	.313	246
314	1	32,740	71.99	7 n r	.0862	.0864	.374	294
314	1	32,740	3610.60	4 r	.1112	.1114	.482	371
314	1	32,740	19.52	10 n r	.0915	.0902	.390	298
332	2	33,400	19.52		.1825			
314	1	32,740	3769.58	2	.1320	.1322	.572	403
314	1	32,740	75.71	9	.0972	.0974	.421	296
314	1	32,740	83.67	8	.1262	.1280	.554	387
319	1	32,500	83.67		.1283			
319	1	32,500	3807.30	8	.1393	.1453	.628	433
314	1	32,740	07.30		.1497			
314	1	32,740	58.40	9 r	.1085			
328	1	32,800	58.40		.1085	.1086	.470	315
332	2	33,400	58.40		.2210			
319	1	32,500	4401.70	9	.1573	.1587	.686	354
319	1	32,500	59.21	9	.1560	.1574	.681	342

[1] λ as given in Exner and Haschek's (spark spectrum) and Hasselberg's (arc spectrum) tables. Wave-lengths on Rowland's scale. Intensities as given above are taken from these two tables. n = nebulous; r = easily reversed.

From the following tables, IX to XI, it will be noted that for nickel the separation does not increase proportionally with the field, else $\frac{\Delta\lambda}{\lambda^2 H}$, as calculated for fields of different strength, would be approximately the same. This probably holds good in the case of cobalt also.

In Tables IXa and XI, $\Delta\lambda_s$ signifies $\Delta\lambda$ in terms of the dividing engine screw, $\Delta\lambda_m$ the mean separation in screw units for $H = 32{,}800$ as calculated from the values of $\Delta\lambda_s$ given for different fields, 32,500, 32,740, and 33,400. The calculation is based on the assumption that for the short intervals employed $\Delta\lambda$ varies proportionally with H; and double weight is given to measurements made on plate No. 332, which was taken in the second spectrum.

TABLE IXb.

Plate 317. $H = 29{,}100$.

Nickel. Lines appearing as triplets.

Spectrum	λ	$\Delta\lambda$	$\frac{\Delta\lambda}{\lambda^2} \times 10^{10}$
2	3775.71	0.384	269
2	83.67	.503	352
2	3807.30	.584	403
2	58.40	.422	290

TABLE X.

$\frac{\Delta\lambda}{\lambda^2 H} \times 10^5$ as calculated from fields of 32,800 and 29,100 c. g. s units.

Nickel.

λ	$H = 32{,}800$	$H = 29{,}100$
3775.71	9.0	9.5
83.67	11.8	12.1
3807.30	13.2	13.9
58.40	9.6	10.0

TABLE XI.[1]

First spectrum. Plates 321, 322, 323, 324, and 329.
Cobalt. Lines appearing as triplets.

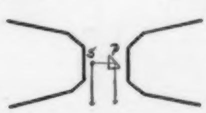
Plate	Field	λ	Intensity	$\Delta\lambda_s$	$\Delta\lambda_m$ $H=32{,}800$	$\Delta\lambda$ (Å. U.) $H=32{,}800$	$\frac{\Delta\lambda}{\lambda^2}\times 10^{10}$
321	32,300	3521.70	6 r	0.1363	0.1377	0.595	480
321	32,300	3704.17	6	.1398	.1412	.610	455
329	32,800	3845.59	9 n	.1158	.1158	.501	339
321	32,500	73.25	9 n	.1208	.1220	.528	355
324	32,200	94.21	10 n r	.0828	.0884	.382	252
329	32,800	94.21		.0925			
324	32,200	3933.32	2	.1235	.1268	.548	354
321	32,500	33.32		.1265			
321	32,500	41.034	5	.1676	.1693	.732	471
323	32,200	41.87	6	.1155	.1169	.505	325
322	32,500	41.87		.1150			
324	32,200	3969.25	5	.1308			
322	32,500	69.25		.1325	.1335	.577	366
329	32,800	69.25		.1332			
322	32,500	4118.92	9	.1008			
321	32,500	18.92		.1067	.1055	.456	269
329	32,800	18.92		.1069			
323	32,200	21.47	9	.1118	.1142	.492	290
322	32,500	21.47		.1133			
323	32,200	4225.28	3	.1100			
324	32,200	25.28		.1145	.1167	.505	283
322	32,500	25.28		.1200			
322	32,500	4629.515	9	.2210	.2232	.965	450

The nickel lines which appear unseparated are: 3423.80, 3483.1,[2] 3510.47, 3518.80, 3597.84.

The values of $\Delta\lambda$ in Tables IX to XI are correct to at least 0.02 Å. U.

4. *The Zeeman effect along the lines of force.*

Previous investigators in examining the Zeeman effect along the lines of force have used a pierced magnet pole. This rendered the field non-uniform and prevented accurate measurement of its strength. To obviate this a small total reflecting prism was used, as shown in the adjoining cut. Two images appear near the spectrometer slit, one giving the spectrum along the lines of force, the other perpendicular to them.



[1] Same notation as table IXa. λ taken from Hasselberg's table (arc spectrum). Wave-lengths on Rowland's scale.

[2] λ as given by Liveing and Dewar.

The prism used was 12 mm long by 2 mm across its perpendicular faces. The crystal was cut so as to have the optic axis parallel to one of the faces of the prism, and perpendicular to its edge. The prism was supported by a delicate adjustable framework bound to the pole-pieces of the magnet and a piece of fine microscopic cover glass protected it from the heat of the spark. Mica may be used when ultra-violet light is desired.

The method proved a success. In one exposure during a period of 70 minutes, the images were alternately focused upon the slit and the shutter in the camera turned accordingly. The direct image was first used for 20 minutes; then the shutter was changed and the image which had passed through the small prism was employed for 30 minutes; then again the direct image for another 20 minutes. The two 20-minute exposures were thus thrown on the edges of the photographic plate, the 30-minute one on the center. Thus would be shown any change of field strength, which, indeed, was a highly improbable occurrence.

Table XII shows that within the limits of error of observation, the separation of the external plane polarized components of the triplet is equal to that of the circularly polarized components of the doublet which is expressed by the symbol $\Delta\lambda_0$.

TABLE XII.

Zinc. $H=18,760$.

Line	Intensity and character	$\Delta\lambda$	$\Delta\lambda_0$	$\Delta\lambda-\Delta\lambda_0$
Zn 4680.38	10 r	0.703	0.700	+0.003
Zn 4722.26	10 r	0.614	0.607	+ .007
Zn 4810.71	10 r	0.422	0.425	− .003

5. *The extension of Preston's law that* $\frac{\Delta\lambda}{\lambda^2 H}$ *is a constant for homologous lines of Kayser and Runge's spectroscopic series.*

This part of the investigation has proved to be one of great interest, and promises even better results if continued under slightly better conditions, notably with a grating which is bright in the second or third spectrum.

The most brilliant lines, especially those of zinc and cadmium, and those of the best character as to symmetry and sharpness, have been repeatedly photographed by various investigators. Preston derived the law mentioned from results of experiments upon the zinc, cadmium, and magnesium lines whose wave-lengths are given approximately by putting n equal to 3 in Kayser and Runge's formula,

$$\lambda^{-1} = A + Bn^{-2} + Cn^{-4},$$

where A, B, and C are constants for any one element. It appeared of interest to investigate the homologous lines of the other metals occurring in the second column of Mendelejeff's chart — that is, of the metals mercury, calcium, strontium, and barium; and also to study the separation of the lines forming the first subordinate series. For barium, Kayser and Runge have found no series. Strontium has only the first subordinate. To obtain in a sharp and measurable form some of the diffuse and unsymmetrical lines of mercury and the diffuse though symmetrical lines of the first subordinate series of some of the members of this chemical group, is a matter of no little difficulty. Total failure has been the result in many cases. It has long been known that self-induction in the spark circuit tends to sharpen diffuse lines. This method has been used and has proved indispensable. A better method would be the use of a vacuum tube. This the author intends to try if later an opportunity offers itself.

In the following investigation the first question was one of the choice of field and magnetic gap. It was advisable to use a large current in the magnetizing coils, for the higher the point chosen in the magnetization curve the less will the field vary for a small given change in the current. Secondly, the gap must be neither too large, else the field would be too weak and the lines of small separation would not be resolved; nor too small, else both the size of spark would be limited and consequently the exposures necessarily prolonged, and also the field would be so strong that the droop on the H-$\Delta\lambda$ curve would enter to a too great degree. A current of 15 amperes in the coils and a gap

of 7 mm were chosen. This combination gave a field of about 26,460 c. g. s. units; much too strong, but quite necessary to resolve some lines, notably *Zn* 3282.42 and *Cd* 3403.74.

By referring to Fig. 2c it will be seen that zinc 4810.71 at $H = 26{,}460$ shows a separation of 0.53 Å. U., while if $\Delta\lambda$ increased proportionately with the field, its value would be 0.71 Å. U. or 34 per cent. greater. Lines homologous with zinc 4810.71 show a similar droop.[1] This explains the discrepancies between Reese's values (Table XV) and Preston's and mine for the three lines—one each in cadmium, mercury, and magnesium—which are homologous with zinc 4810.71. Of the other lines investigated by me, it must be said that the characters of all the curves are not known. To obtain the variation of $\Delta\lambda$ with the field for all would call for more labor than time at present permits.

Tables XIVa and XIVb go together, the homologous lines occupying homologous positions. Table XIII contains the data on which are based the tables following it. Certain points should be noted relative to some of the lines given in this table.

Cadmium 3252.63 was difficult to measure because of small intensity, but the value of the separation given is probably accurate to 5 per cent.

Mercury 5460.97 and magnesium 5183.84 are unsymmetrical. The value of $\Delta\lambda$ given for each represents the distance between the center of the symmetrical violet component and the most dense portion of the red component, which latter is sharp on the violet edge and shades off toward the red. Zinc 4810.71 is somewhat similar but the asymmetry is not so marked, while cadmium 5086.06 shows less, but still some asymmetry. These four lines are homologous.

Strontium 4832.23 is also peculiar, but here the violet component is shaded toward the red, while the red component is symmetrical. Moreover, the violet component is more intense than the red. Strontium 4876.35 shows the same difference in intensity but both components are symmetrical.

[1] REESE, ASTROPHYSICAL JOURNAL, **12**, 128, 1900.

TABLE XIII.

$H = 26{,}460$.

Metal	λ[1]	Intensity and character	$\Delta\lambda$	$\frac{\Delta\lambda}{\lambda^2} \times 10^{10}$
Zn	4680.38	10 r	0.959	0.438
	4722.26	10 r	.859	.394
	4810.71	10 r	.544	.235
	3282.42	8 r	.146	.135
	3303.03	8 r	.245	.225
	3345.62	8 r	.337	.301
Cd	4678.37	10 r	.947	.433
	4800.09	10 r	.890	.386
	5086.06	10 r	.619	.239
	3252.63	8 bv	.308	.291
	3403.74	10 r	.152	.131
	3467.76	8 r	.275	.228
	3613.04	8 r	.391	.299
Hg	4046.78	6 r	.726	.442
	4358.56	10 r	.738	.388
	5460.97	10 r	.683	.229
Mg	3838.44	10 r	.432	.293
	5167.55	8 r	1.140	.427
	5172.87	10 r	1.058	.374
	5183.84	10 r	0.643	.239
Ca	4425.61	10 r	.246	.125
	4435.86	8 r	.425	.216
	4456.08	8 r	.594	.298
Sr	4832.23	10 r	.792	.339
	4876.35	8 r	.785	.330

Also *approximately*[2] (*i. e.*, to 10 per cent.).

Metal	λ[1]	Intensity and character	$\Delta\lambda$	$\frac{\Delta\lambda}{\lambda^2} \times 10^{10}$
Ca	6122.46	10 r	1.50	0.400
	6162.46	10 r	1.05	.274

1. Kayser and Runge's tables (arc spectrum). Wave-lengths, Rowland. r means "easily reversed;" bv stands for "band with sharp edge toward the violet."

2. Lines faint, and so only approximate measurements were made.

Magnesium 3838.44 is unsymmetrical in the same way as mercury 5460.97, but is probably correct to 0.01.

The three calcium lines 6102.99, 6122.46, 6126.46, all strong lines visually, could not be obtained by the method used with other lines, although an "Erythro" plate of the International Color-Photo Company was exposed to the radiation for four

hours. However, by throwing upon the upper terminal of the spark gap a continuous and rather large jet of a saturated solution of calcium chloride 6122.46 and 6162.46 were obtained in measurable form after an exposure of about 90 minutes.

The lines of the spectroscopic series which do not appear in Table XIII either could not be obtained because of (1) low intensity or (2) their position in the spectrum (below λ 3300 or above λ 5800), or could not be measured because of their diffuse character. Self-induction in the discharge circuit improved the condition of some lines and removed the air spectrum, but did not sufficiently narrow diffuse lines in all cases.

The values of $\frac{\Delta\lambda}{\lambda^2}$ in Table XIII are correct in general to 0.01 Å. U. Probably, however, $\Delta\lambda$ for zinc 3282.42 (also cadmium 3403.74 and calcium 4425.61) is not so accurate. The separation is small and the measurement of such a line is made with difficulty.

Table XV explains itself. Table XVI is taken from the mean values given in Table XV. Reese's values of $\Delta\lambda$ were obtained from the slope of the curves, and therefore no corrections are necessary in $\frac{\Delta\lambda}{\lambda^2 H}$. Correcting my values for $n = 3$, in the second subordinate series, by adding 3, 3 and 34 per cent. respectively; and treating the values for the three sets of lines for which $n = 4$ in the first subordinate series, and the one set for which $n = 4$ in the second subordinate series in a similar manner, because they give H–$\Delta\lambda$ curves homologous to those given by the $n = 3$, second subordinate sets;[1] also, raising by 16 per cent. Preston's mean value for the third set in $n = 3$, second subordinate series (see curve Fig. 2c) we obtain the results given in Table XVI. This table shows:

1. That Preston's law, that $\frac{\Delta\lambda}{\lambda^2 H}$ is a constant for homologous lines, established by him for the homologous lines of zinc, cadmium, and magnesium given by $n = 3$ in the second subordinate series, appears to hold for the homo logous lines in mercury and cadmium.

[1]This fact I have verified by experiment upon cadmium 3613.04 and cadmium 4425.61.

TABLE XIVa.

Lines of spectroscopic series investigated.

Metal	First subordinate series			Second subordinate series					
	$n=4$			$n=3$			$n=4$		
Zn	3282.42	3303.03	3345.62	4680.38	4722.26	4810.71	......	......	......
Cd	3403.74	3467.76	3613.04	4678.37	4800.09	5086.06	......	......	3252.63
Hg	......	......	......	4046.78	4358.56	5460.97	......	......	......
Mg	......	......	3838.44	5167.55	5172.87	5783.84	......	......	......
Ca	......	......	......	......	6122.46	6162.46	4425.61	4435.86	4456.08
Sr	4832.23	4876.35	......	......	......	......	......	......	......

TABLE XIVb.

$\frac{\Delta\lambda}{\lambda^2}\times 10^{10}$ or lines given in homologous positions in Table XIVa.

Metal	First subordinate series			Second subordinate series					
	$n=4$			$n=3$			$n=4$		
Zn	135	225	301	438	394	235	...	...	...
Cd	131	228	299	433	386	239	...	...	291
Hg	...	...	...	442	388	229	...	...	...
Mg	...	...	293	427	374	239	...	...	...
Ca	...	...	...	...	400	274	125	216	298
Sr	339	330	...	...	...	...	...	...	...

2. That, within the limits of accuracy of measurement, $\frac{\lambda}{\lambda^2 H}$ is the same for homologous lines given by $n=4$ in both the subordinate series for zinc, cadmium, mercury, magnesium, and calcium. This assumes that the lines not investigated show values of $\frac{\Delta\lambda}{\lambda^2 H}$ which are the same as those investigated in each set—an assumption which is certainly not unjustifiable.

3. That the average value of $\frac{\Delta\lambda}{\lambda^2 H}$—obtained from Preston's, Reese's, and my determinations—for the third set in $n=3$, or $\frac{1}{3}(12+10.7+11.1)=11.27$, is so related to the average value of $n=4$ (as given in the same table, XVI) for the homologous sets in both subordinate series, or $\frac{1}{2}(15.1+14.9)=15.00$, that $\left(\frac{\Delta\lambda}{\lambda^2 H}\right)_{n=3} : \left(\frac{\Delta\lambda}{\lambda^2 H}\right)_{n=4} :: 3 : 4$; as $\frac{1}{3}(11.27)=3.76$, while $\frac{1}{4}(15.00)=3.75$. Thus, if we assume $\frac{\Delta\lambda}{\lambda^2 H}$ proportional to $\frac{e}{m}$,

where "e" is the amount of electricity carried by the particle of mass "m", we may say that the ratio of the charge to the mass of the particle varies directly with "n" for the third set of lines in the second subordinate series where "n" has either the value 3 or 4.

TABLE XV[1].

$$\frac{\Delta\lambda}{\lambda^2 H}\times 10^5$$

Metal	First subordinate			Second subordinate											
	$n=4$			$n=3$									$n=4$[4]		
				Calculated from Table XIVb			Reese[2]			Preston[3]					
Zn	5.1	8.5	11.4	16.5	14.9	8.9	17.0	15.3	11.3	17.	14.8	9.53	....	....	....
Cd	5.0	8.6	11.3	16.4	14.6	9.1	17.0	15.5	10.5	....	....	....	....	....	11.0
Hg	....	..	....	16.7	14.7	8.7	16.7	....	10.3	....	....	....	....	....	....
Mg	....	....	11.1	16.1	14.1	9.0	16.7	14.9	10.5	....	....	....	....	....	....
Ca[5]	....	....	....	....	15.1	10.4	....	....	....	....	....	....	4.8	8.2	11.3
Sr[5]	12.8	12.5	....	....	....	....	....	....	....	....	....	....	....	....	....
Mean	5.1	8.6	11.3	16.4	14.6	8.9	16.9	15.2	10.7	17.	14.8	9.5	4.8	8.2	11.2

1. Field 26,460.
2. Reese's values calculated from slope of curve on *H* diagrams.
3. Approximate mean value given by Preston for the homologous lines of *Zn*, *Cd*, and *Mg*. $H=20{,}000$.
4. Calculated from data given by Reese. See his article before mentioned, ASTROPHYSICAL JOURNAL, **12**, 129, Sept. 1900.
5. Excluding strontium, as it is irregular, and calcium, $n=3$, the measurements of which are but approximate. Note that the calcium lines agree quite well with the homologous lines in *Zn*, *Cd*, *Hg*, and *Mg*.

TABLE XVI.

$$\frac{\Delta\lambda}{\lambda^2 H}\times 10^5\text{, corrected values.}$$

	First subordinate			Second subordinate											
	$n=4$			$n=3$									$n=4$		
				Table XIVb			Reese			Preston					
	5.2	8.8	15.1	16.9	15.0	12.0	16.9	15.2	10.7	17.	14.8	11.1	4.8	8.4	14.9
Set	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3

(The first subordinate series shows no lines for $n=3$. The value 15.1 was averaged with 14.9 because of the probability of obtaining thus a more correct mean).

4. That there appears to be no relation between sets 1 and 2, $n=4$ and 1 and 2, $n=3$, or, taking total mean values, between

16.9, 15.0 for $n=3$ and
5.0, 8.6 $n=4$.

However, inasmuch as the wave-lengths of the three lines forming the spectroscopic triplet are so related to each other that, given that of one of them, the wave-lengths of the other two can be calculated, thus forming a connection between the members of the triplet, we would not expect that here again a relation would appear between the first, second, and third lines of the triplet in any one series, unless, indeed, it were a relation equivalent to that just mentioned, namely, the possibility of the calculation of the wave-lengths of the two lines of the triplet given that of any one.

GENERAL SUMMARY.

The most important results obtained in this investigation are briefly as follows:

1. That for iron and nickel as well as zinc the Zeeman effect is not proportional to the field strength for high values of the latter.

2. That the divisions of large and small pressure shift in the case of iron are not absolutely the same as those of large and small Zeeman separation. Of 34 lines investigated, 26, or about 76 per cent., show both large pressure shift and large separation, or small pressure shift and small separation; while 8, or 24 per cent., show either small pressure shift and large separation, or large pressure shift and small separation.

3. That there is apparently no simple law connecting the separation of the various lines in either iron, nickel, or cobalt.

4. (*a*) That Preston's law, $\frac{\Delta\lambda}{\lambda^2 H}$ = constant, holds for the homologous lines given by $n=3$ for mercury and calcium as well as zinc, cadmium, and magnesium. (*b*) That Preston's law also

holds for the homologous lines given by $n=4$ in *both* the subordinate series of zinc, cadmium, magnesium, and calcium. (c) That the ratio of the charge carried to the mass of the particle carrying it varies directly as "n" for the third set of lines in the second subordinate series, when "n" has the value either 3 or 4. This, of course, assumes that the ratio of charge to mass varies directly as $\frac{\Delta\lambda}{\lambda^2 H}$.

In this investigation the author was assisted at various times by Messrs. J. H. Moore, J. E. Routh, R. E. Loving, G. W. Middlekauff, J. T. Barrett, and W. J. Crist.

In conclusion I wish to acknowledge the debt I owe to Professors H. A. Rowland and J. S. Ames for their valuable advice and encouragement.

PHYSICAL LABORATORY,
JOHNS HOPKINS UNIVERSITY,
June 1901.

ON THE MOTION OF *a PERSEI* IN THE LINE OF SIGHT.[1]

By H. C. VOGEL.

IN *Monthly Notices*, Vol. LXI, No. 1, Mr. Newall, of Cambridge, England, calls attention to the fact that the velocity of *a Persei* in the line of sight, as deduced from observations on eleven evenings in September and October 1900, and three evenings in October 1899, varies from -4 km to $+8$ km, and he suspects a period of variability of 4.2 or 16.8 days. Since the Cambridge weather conditions in winter do not admit of continuous observations, Mr. Newall requests that the motion of the star be observed elsewhere. His observations were made with a new four-prism spectrograph of powerful dispersion attached to his large refractor of 63 cm aperture.

According to the data given on p. 12 of the above mentioned article, a difference in wave-length of 0.6 $\mu\mu$ on the spectrograms obtained last year corresponds to a linear distance of 1 mm, and a displacement of this amount to a velocity of 400 km. Nothing more definite is said as to the line to which these values refer; it is, however, clear from the above that the scale of the plates is very considerable, and about double that of the Mills spectrograph of the Lick Observatory or of the new spectrograph for the great Potsdam refractor.[2]

In view of our unfavorable conditions at Potsdam as regards steadiness of air, which of late years have been quite unusual, I had early arrived at the conclusion that spectrographic work with the large refractor would make but slow progress under further continuance of such state of air. Accordingly, toward the close of the year 1899 I designed a spectrograph for our excellent photographic short-focus refractor of 32 cm aperture and 3.44 m focal length, which was constructed by Toepfer of Potsdam and completed in the spring of 1900. In the course of

[1] Translated from author's proofs from *Sitzungsberichte der k. Akad. zu Berlin.* Session of Jan. 17, 1901.

[2] See my summary in ASTROPHYSICAL JOURNAL, 11, 399, 1900.

the summer it was subjected to an exceedingly thorough investigation and carefully corrected by Dr. Eberhard according to the method given by Dr. Hartmann.[1]

The triple collimator objective has a focal length of 30 cm; the camera objective, which is also triple, a focal length of 35 cm. The three prisms give a spectrum which is measurable and uniformly sharp between λ 4120 and λ 4420, the extent of this section of spectrum being 20 mm. At the center (λ 4250) a linear displacement of 0.25 mm (1 rev. of the screw of the measuring machine) corresponds to a motion of 261 km; at $H\gamma$ (λ 4340) the same displacement corresponds to 291 km. The instrument gives only about two fifths of the linear extent of Newall's apparatus. The spectrograph is enclosed in a case which is provided with means for maintaining the temperature constant to within 0°.1 C.

With this instrument Dr. Eberhard made photographs of the spectrum of *α Persei* on six nights (1900, Nov. 3, 5, 6, 8, 9, and 15), and four of these plates (Nov. 3, 5, 6, and 9) I measured in order to test the utility and efficiency of the apparatus for its proper purpose, as it had previously been investigated almost wholly in the laboratory. The spectra were good, and the measures of the four plates gave no deviations which would have allowed us to infer variations of motion of more than 2 km. The observations were, however, affected with one error which had its cause in a slight mechanical imperfection in the instrument that could not be observed in the laboratory investigations. After the correction of this defect and a further test of the apparatus by Dr. Eberhard, I regarded the instrument suitable to continue the observations by Newall, which had been published in the meantime.

The first two photographs in the list given below were made by Dr. Eberhard; the others by Dr. Ludendorff. The measurement of the spectrograms I undertook myself; it consists solely in the determination of the differences between the lines of the *Fe* spectrum and the corresponding lines of the star spectrum,

[1] *Zeitschrift für Instrumentenkunde*, 1900; ASTROPHYSICAL JOURNAL, **11**, 400; **12**, 30, 1900.

and the number of lines compared in the several spectra varies from 14 to 21. Although the spectrum of the star is to be classed among those with few lines, since, strictly speaking, it does not belong to spectral class IIa, but forms the transition from class Ia_3 to IIa, still 140 to 150 lines upon the better photographs are to be counted between $\lambda 4119$ and $\lambda 4415$; most of these lines, moreover, are extraordinarily sharp, owing to the fact that the slit width in the photographs of *a Persei* amounted to but 0.015 mm. Consequently, the spectra admits of a far more rigorous treatment than I at first undertook at this point. The final results, therefore, may still receive slight changes, which, indeed, would arise on measuring the displacement of the same lines in reference to the comparison spectrum in the reversed position of the spectrogram under the microscope. My measurements have been in but one direction, that in which increasing readings upon the screw of the measuring instrument correspond to greater wave-lengths. The changes mentioned have, however, no significance as regards the proof of a possible variation in the velocity, of the amount mentioned at the beginning of this article, and the observations are accordingly to be regarded as provisional only so far as the absolute amount of the star's motion in the line of sight is concerned.

OBSERVATIONS OF a *PERSEI*.

Date 1900–1901	Potsdam Mean Time	Temperature Centigrade	Number of plate	Velocity in ref. to Earth	Reduction to ⊙	Velocity in ref. to ⊙
Dec. 13	$7^h\ 56^m$	+ 5°.4	416	+ 7.8 km	− 9.4 km	−1.6 km
14	7 11	+ 5.7	417	+ 6.2	− 9.8	−3.6
18	5 7	+ 5.1	418	+ 8.8	−11.4	−2.6
20	5 5	+ 3.8	419	+10.6	−12.2	−1.6
21	9 17	+ 5.0	420	+ 9.3	−12.7	−3.4
22	5 21	+ 4.7	421	+10.2	−13.0	−2.8
Jan. 1	5 5	− 5.9	422	+12.4	−16.8	−4.4
2	5 1	− 9.3	424	+13.4	−17.2	−3.8
3	5 10	−10.0	426	+12.6	−17.5	−4.9
4	5 1	− 9.4	427	+14.4	−17.8	−3.4
5	4 55	− 9.2	429	+13.8	−18.2	−4.4
9	5 18	− 3.3	432	+16.6	−19.4	−2.8
9	6 32	− 2.8	433	+16.9	−19.5	−2.6
						−3.22

The spectrograms are almost without exception to be described as very good. In plate 417, however, the star spectrum is rather weak, and hence the measures are slightly less accurate. Morever, in plate 420 the *Fe* spectrum, and in plate 422 both the star and the *Fe* spectra are somewhat weak. In plate 426 the star lines are rather broad.

The preceding observations furnish no confirmation of Newall's results, since the largest deviations of the values obtained for the several evenings from the mean value are but −1.6 km and +1.7 km — deviations which may permissibly occur with the degree of accuracy attained in these observations. The probable error of a determination of the displacement between a line in the star and a line in the comparison spectrum varies between ±1.2 km and ±2.2 km for the different plates. Consequently the probable error of the mean value obtained from the measures of a plate would amount to from ±0.3 km to ±0.6 km. Experience shows it to be somewhat larger, and in the above case, as derived from the deviations of the values of the several plates, it amounts to ±0.69 km.

As I have already said, my results for the absolute value of the velocity of *α Persei* in the line of sight are as yet not to be considered definitive. Their close agreement with Campbell's observations, viz.,

1896	Nov.	11	−2.0 km
		12	−1.8
1897	Jan.	19	−3.5
1898	July	12	−2.1
			−2.4 km

is, however, worthy of note, and may well vouch for the invariability of the star's motion within narrow limits.

THE SPECTROSCOPIC BINARY *MIZAR*.[1]

By H. C. Vogel.

Shortly before 1890 photographic plates of the spectrum of *Mizar* (ζ *Ursae Majoris*) obtained at the Harvard College Observatory showed the brighter component of this well-known double star to be itself a binary, and from the extensive observational data[2] it was also inferred that both of these components are bright, and give spectra belonging to Class I. The motion of the components is shown by an occasional brief doubling of the spectral lines which occurs with fair regularity at intervals of fifty-two days, and the displacements of these lines give a maximum relative velocity of the two bodies of about 100 miles (160 km). According to Pickering[3] the assumption of a strongly eccentric orbit, with a major axis nearly perpendicular to the line of sight, agrees well with the observations. Consequently, only at the time of periastron, once in every 104 days, would the components of motion in the line of sight attain a sufficient value to allow of the separation of the lines of the composite spectrum formed by the overlying spectra of the two bodies. At apastron, in consequence of the slight orbital velocity, the lines would merely appear diffuse or considerably broadened. The Cambridge observations, however, show various irregularities to exist, so that up to the present time the relations in the system are to be regarded as not yet entirely explained.

The Potsdam observations of 1889 and 1890 are too few in number and too far apart in time to contribute toward the settlement of the question. Such is far from being the case, however, with the very excellent plates of this interesting double star

[1] Translated, at the author's request, from *Sitzungsberichte der k. Akad. zu Berlin*. Session of May 2.

[2] One hundred and thirteen photographs, eighty evenings of observation.

[3] *Monthly Notices*, R. A. S, 50, 297.

secured in March and April of the present year by Dr. Eberhard and Dr. Ludendorff with spectrograph IV of the 33 cm refractor. I have undertaken the measurement of these plates myself, and make the following preliminary announcements of the results, which are in complete contradiction to the previous views as to the system.

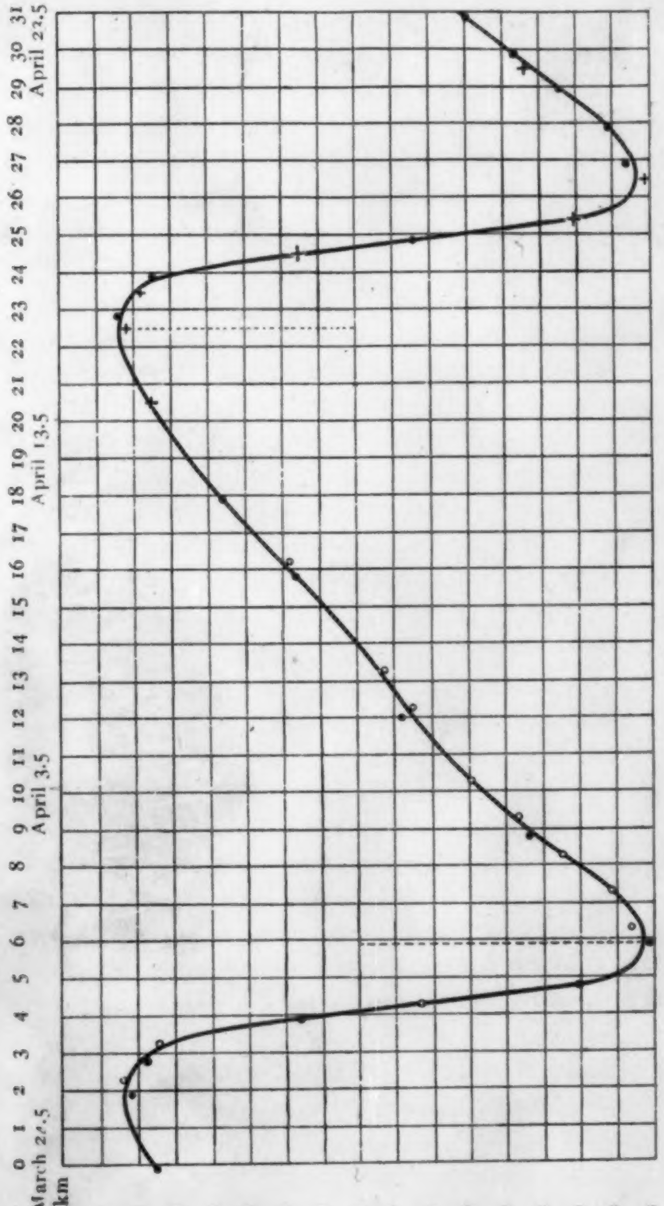
It is to be noted of the spectra themselves that they have few lines (Class Ia 2); at the time when the spectral lines of the two components nearly coincide, however, several of the strongest lines of the *Fe* spectrum and of a few other elements (as *Si*) in the part of the spectrum investigated (λ4120 to λ4500) appear as delicate lines, in addition to the broad $H\gamma$ and the strong *Mg* line at λ4481 which is always present. Thus on plate 602, obtained April 27, sixty-five lines are easily recognizable. When the spectra are more strongly displaced with reference to one another, most of the lines, which then appear double, become so weak that the measurement of their separation is rendered very difficult. On some plates, in fact, it was found possible to measure only the *Mg* line λ4481; especially good plates admitted of the measurement of some *Fe* lines as well, and, in case of exceptionally wide displacement, of $H\gamma$ also. It is to be noted that the fine lines of the spectra of Class Ia 2 are only obtained when the exposure time is exactly correct, and the plate is carefully developed. In general, the measures are to be classed as difficult, either on account of the excessive fineness or, in case of the *Mg* and *H* lines, on account of the too great breadth and diffuseness of the lines.

On several plates the *Mg* lines appear of unequal breadth, and I have endeavored to see whether I could observe a change in their behavior after a coincidence[1]—as I succeeded in doing in the case of *β Aurigae*, in which, as is well known, a periodic doubling of the spectral lines occurs, but up to the present time I have arrived at no accordant results. I do not, however, consider it as impossible that a larger number of observations would give certainty on this point.

[1] *Publicationen des Astrophysikalischen Observatorium*, Bd. VII, p. 143.

Date		Potsdam Mean Time	Number of plate	Relative motion
1901 March	24	$9^h\ 37^m$	537	111 km
	26	9 52	542	124
	27	8 6	546	117:
	28	10 22	549	31
	29	7 19	550	119
	30	8 33	554	158
April	2	8 8	556	93
	5	8 32	559	19
	5	11 12	561	23
	5	14 20	563	31
	5	16 15	565	21
	9	8 24	570	33
	11	9 7	573	73:
	16	8 25	575	128
	17	8 30	577	109
	18	8 24	578	32
	20	8 22	580	148
	21	8 37	586	138
	22	8 20	589	111
	23	8 22	594	87
	24	8 49	597	61
	26	9 21	600	30
	27	9 24	602	15
	30	10 7	604	36
May	1	11 28	605	63

Measures of the motions of the system in the line of sight have also been secured upon plates in which the lines cannot be recognized as double. These, however, are of no great accuracy, since the distances between the individual lines of the star spectrum and the corresponding lines of the *Fe* spectrum exhibit greater variations than is to be expected upon plates made with this excellent apparatus. The reason for this may lie in the fact that with incomplete coincidence of the spectra the components of the different pairs of lines do not possess the same differences of intensity: thus, if in one of the apparently single lines the component lying toward the red were the stronger, and in another that lying toward the violet, a different estimate of the center would be formed in the two cases. Finally, in order to be able to draw some conclusion as to the ratio of the masses of the two bodies, I have tried to see whether a displacement of the centers of the pairs of lines in reference to the corresponding lines of the comparison spectrum occurs at the different phases when allowance



THE SPECTROSCOPIC BINARY *MIZAR*

is made for the motion of the system in the line of sight. The material so far secured has, however, proved insufficient for this investigation. The observation of the star will be continued with a view to detecting relations of this sort, but especially to determining the period accurately enough to establish a connection with the earlier observations.

The motion of the system according to my measures amounts to -16 km per second.

I have drawn in the figure the curve which agrees best with the results of the measures, the period used being 20.6 days. The observations of the first period are represented by points; those of the second period carried back to the first by small circles; while the points carried over from the first period to the section of the second period included in the drawing are denoted by crosses. The following provisional elements have been computed from the curve by Dr. Eberhard according to the method of Lehmann-Filhés,[1] on the assumption: $P = 20.6$ days, $A = 128$ km, $B = 156$ km, A and B being the maximum relative intensities in the line of sight.

$T_0 = 1901$ March 28.60 (Relative motion in line of sight $= 0$)
$T = 1901$ March 28.88
$\omega = 101.^\circ 3$
$e = 0.502$
$\log \mu = 9.4843$
$\mu = 17.^\circ 476$
$a \sin i = 35$ million kilometers

$$m + m_1 = \frac{4 \odot}{\sin^3 i}.$$

A curve computed from these elements agrees well with that drawn directly from the observations.

[1] *A. N.*, **136**, 17, 1894.

STANDARD LINES IN THE ARC SPECTRUM OF IRON.[1]

By H. KAYSER.

THE only really reliable method of determining wave-lengths is by producing in the spectrum under investigation a number of lines whose wave-lengths are accurately known. If we were reducing a photograph taken with a concave grating—hence a normal spectrum—a linear interpolation between two known lines at the end of the portion of spectrum would furnish approximate wave-lengths of the unknown lines intervening. But the spectrum is neither perfectly normal, nor is the measuring apparatus free from errors; and, moreover, there are errors in the standards themselves and in the settings made upon them. Hence a much greater accuracy is secured if we have at our disposal a greater number of standards between the terminal lines. The differences are then taken between the known wave-lengths of the standards and the wave-lengths computed from the terminal lines, and a curve is obtained by the method of least squares, or better graphically, which, instead of a straight line, best fits the measurements of the known lines. The measurements of the unknown lines are then corrected accordingly.

It is evidently desirable to have a large number of standards.

If the spectra are to be produced in the arc, iron lines are most convenient as standards, since the carbons contain so much iron that a large number of the principal lines will appear of themselves, and, if desired, some salt of iron, or the metal itself, may be introduced into the arc.

The basis of all determinations of wave-lengths for a long time to come will doubtless be Rowland's table,[2] which was obtained by the method of coincidences. It also includes many lines of the arc-spectrum of iron, but these are unfortunately not

[1] *Annalen der Physik* (4), **3**, 1900.

[2] *Phil. Mag.* (5), **36**, 49–75, 1893.

sufficient in number in all parts of the spectrum. The table gives the following number of such lines per hundred units from λ 2300 on, in the direction of greater wave-lengths; 8, 14, 13, 3, 17, 8, 17, 23, 3, 3, 3, 12, 7, 18, 22, 7, 4. Beyond λ 4000 the number becomes still less, and there are almost none beyond λ 4500.

Hence there is a pressing need of further measurements of the iron spectrum having an accuracy equal to that of Rowland's standards.

In beginning our investigations on the arc-spectra of the elements[1] Professor Runge and I accordingly first determined the iron spectrum. As Rowland's table had not then been published we had insufficient auxiliaries; and as they were our first measures, for which we thought we could be content with an accuracy of 0.1 tenth-meter, they did not turn out particularly well, and today they are entirely inadequate. Beside this, they were based upon a different value for the D lines than that later adopted by Rowland. Hence Runge and I later published a short list[2] of new measures on which our subsequent publications were based.

The accuracy of all measurements has meanwhile increased very considerably, and a limit of error of only a few thousandths of a tenth-meter is well attainable for sharp lines. I therefore undertook a new measurement of the iron spectrum for my determination of the spectra of the platinum group.[3] I have now made still another set of measures and I believe I have reached the limit of accuracy attainable with Rowland gratings, viz., for all lines a mean error of at most 0.003 tenth-meter.

My measures depend exclusively upon Rowland's standards, but in addition to his iron standards those of other elements have been employed, *Ni*, *Co*, *Mn*, *Ti*, *Mg*, *Ca*, *Sr*, *Zn*, *In*, *Ba*, etc., being introduced into the iron arc. It was thus possible to obtain a sufficient accuracy in those portions, as from λ 3200 to

[1] *Sitzungsberichte der k. Akad. d. Wissenschaft zu Berlin*, 1888.

[2] *Ibid.*, 1890. Also *Wied. Ann.*, **41**, 302, 1890.

[3] *Ibid.*, 1897.

λ 3500, where Rowland's iron standards are absolutely inadequate. The standards are exclusively from the arc-spectrum, however, and never from the solar spectrum, for reasons presently to be mentioned.

It was Rowland's opinion that the error of none of his standards would exceed 0.01 tenth-meter. I believe, however, that it is larger in a very few instances, and such cases will be found on comparing my list with Rowland's. On the whole I think my values are more accurate than his, since the errors will balance each other in the large number of measures. Every wave-length in the following table is the mean of from six to fifteen determinations, on photographs made in different years and with three different gratings in different orders. The mean error lies between 0.001 and 0.003 tenth-meter.

This work might be thought superfluous, as Rowland has also published the wave-lengths of all the iron lines in his list of Fraunhofer lines. We must not forget, however, that with the accuracy aimed at here the wave-lengths of the solar lines are by no means to be regarded as identical with those of the same lines in the arc. A glance at Rowland's table shows what differences may occur for the two cases, even exceeding 0.2 tenth-meter. It appears, moreover, from the early observations of Lockyer on the varied displacements and distortions of the lines of the same element in Sun-spots, and from Jewell's observations, as if the different lines of iron, for instance, originated in different layers of the solar atmosphere where different conditions of pressure prevail. It is then entirely unpermissible to employ the wave-lengths of the solar spectrum for terrestrial spectra. For this reason I have not taken any solar lines from Rowland's table of standards.

The region near λ 3400 offers special difficulties. Rowland has two standards near λ 3306, then follow one at 3389, two at 3406, one at 3427, and several from 3440 on. In my opinion the standards at λ 3389, 3406, and 3427 are all given a value too large by 0.02 to 0.03 tenth-meter. My correction curves depending on these lines always showed a quite impossible bend at

λ 3400, so that I was finally compelled to omit these standards. That I hit upon the right thing in so doing is rendered probable by the fact that the values I obtained for these lines agree well with Rowland's determinations in the solar spectrum.

The following table gives a number of iron lines entirely sufficient for the purpose of interpolation in the region of spectrum between λ 2300 and 4500 photographable with ordinary plates. Those lines have been chosen which appear most readily and at the same time are as sharp as possible, hence the most easily reversible lines. The intensities depend upon quite rough estimates, and range from 1 for the faintest to 10 for the strongest lines. *r* indicates that the line easily shows a self-reversal, *u* that its edges are not sharp. Rowland's standards in the arc-spectrum, and in some few cases in the solar spectrum, are added for comparison.

In the later photographs and computations I have been assisted by Dr. H. Konen.

Wave-length	I.	Rowland	Wave-length	I.	Rowland	Wave length	I.	Rowland
2327.468	3	....	2413.393	4*r*	....	2493.331	7*r*	....
31.384	3	....	24.231	3	....	2496.625	4*r*	....
32.869	3	....	31.126	2	....	2501.228	8*r*	2501.223
43.567	3	2343.571	38.274	2	....	07.991	4*r*	....
48.196	2	....	39.834	4*r*	....	10.927	8*r*	2510.934
48.380	2	2348.385	40.201	4*r*	....	11.857	3	....
54.969	2	....	42.658	4*r*	....	17.754	2	....
59.187	3	....	47.808	4*r*	2447.785	18.198	8*r*	2518.188
64.904	2	2364.897	53.568	2	....	22.950	20*r*	2522.948
68.670	2	....	57.686	5*r*	2457.680	23.754	4*r*	....
73.813	3*r*	....	62.279	4*r*	....	24.393	5*r*	....
75.273	3	....	62.740	10*r*	2462.743	27.525	10*r*	2527.530
79.355	3	....	65.244	5*r*	....	29.223	8*r*	....
80.840	4	....	68.974	4*r*	....	29.928	6*r*	....
82.114	7*r*	2382.122	72.436	4*r*	....	33.911	4	....
83.324	3	....	72.976	10*r*	2472.974	35.699	6*r*	2535.699
84.473	3	....	74.906	4*r*	....	37.263	4*r*	....
88.711	2	2388.710	79.872	10*r*	2479.871	41.064	8*r*	2541.058
90.058	2	....	83.361	20*r*	2483.359	42.192	5*r*	....
95.709	5*r*	2395.715	83.618	3*r*	....	44.016	4*r*	....
2399.322	5*r*	2399.328	84.280	8*r*	2484.283	46.072	10*r*	2546.068
2404.519	3	....	87.155	2*r*	....	49.708	8*r*	2549.704
04.969	5*r*	2404.971	88.232	10*r*	2488.238	51.192	3	....
06.742	5*r*	2406.743	89.844	8*r*	2489.838	56.963	2	....
10.601	5*r*	2410.604	90.737	10*r*	2490.723	62.619	5	....
2411.152	4*r*	....	2491.249	10*r*	2491.244	2567.001	4	....

Wave-length	I.	Rowland	Wave-length	I.	Rowland	Wave-length	I.	Rowland
2574.462	2	....	2747.080	5r	....	2973.254	8r	2973.255
75.845	3	....	50.238	10r	2750.237	73.366	5r	2973.358
78.012	3	....	55.834	5r	2755.837	76.253	3	....
82.408	2	....	56.412	4r	2756.427	81.565	7r	2981.575
84.623	5r	2584.629	57.413	4r	....	83.690	10r	....
85.964	3	2585.963	61.883	5r	2761.876	87.410	4	2987.410
88.102	5r	....	62.125	5r	2762.110	90.511	4	....
98.456	5r	2598.460	68.621	5r	2768.630	94.554	10r	2994.457
99.483	5r	2599.494	72.205	8r	2772.206	2999.630	8r	2999.632
2599.663	4r	....	78.327	6r	2778.340	3001.068	10r	3001.070
2606.920	3r	....	81.936	3	2781.945	07.262	2	3007.260
07.155	3r	....	88.207	10r	2788.201	07.409	2r	3007.408
11.963	5r	2611.965	91.989	3	....	08.254	8r	3008.255
13.914	4r	....	2797.877	2	....	09.690	4r	3009.696
17.706	4r	....	2804.622	5r	....	16.305	3	3016.296
18.108	2r	....	07.088	5r	....	17.747	8r	3017.747
20.499	3	....	13.391	8r	2813.388	19.105	4	3019.109
23.627	5r	....	17.612	3	....	20.619	4r	3020.611
25.754	5r	....	23.382	5r	2823.389	20.764	10r	3020.759
28.383	5r	....	25.660	6r	2825.667	21.194	10r	3021.191
31.139	5r	2631.125	25.803	4r	....	24.153	3r	3024.154
35.899	3r	....	32.543	8r	2832.545	25.960	8r	3025.958
44.085	3r	....	35.562	4r	....	31.753	4r	....
47.649	3	....	38.231	3r	2838.226	37.505	10r	3037.505
51.800	2	....	43.742	3r	2843.744	41.753	3	....
56.232	3	....	44.083	8r	2844.085	41.860	3	....
66.897	3r	....	48.828	3	....	47.719	10r	3047.720
69.581	2	....	51.910	5r	2851.904	51.179	3	3051.173
73.315	2	....	59.007	3	....	57.562	8r	3057.557
79.148	8r	2679.148	63.973	3	....	59.202	10r	3059.200
80.544	3	....	69.418	5r	....	64.042	2	....
89.302	..	....	74.284	5r	....	67.363	8r	3067.363
90.153	2	....	77.414	3	....	68.286	3	....
2699.193	3	....	80.867	2	....	75.830	6r	3075.849
2706.672	4r	2706.684	87.920	3	....	83.853	5r	3083.849
08.663	2	....	90.000	3r	....	91.687	3	....
14.503	3	....	94.617	3	....	3095.013	2	3095.003
18.530	4r	....	2899.531	3	....	3100.057	4r	3100.064
19.121	10r	2719.119	2901.496	3	....	00.418	4r	3100.415
20.997	10r	2720.989	07.630	3	....	00.778	4r	3100.779
23.671	8r	2723.668	12.273	8r	2912.275	12.183	2	....
25.024	4r	....	18.144	3	....	16.747	3	....
28.914	3	....	23.409	5	....	19.609	3	....
30.832	3	....	26.699	3	....	25.770	3	....
33.978	8r	2733.973	29.119	8r	2929.127	32.627	5r	....
35.566	8r	....	37.030	10r	2937.020	40.503	3u	....
37.407	10r	2737.405	41.462	8r	....	42.565	3u	....
39.639	8r	....	47.996	9r	2947.993	44.096	3u	....
42.349	5r	....	48.557	4	....	51.460	3u	....
42.506	10r	2742.485	54.061	9r	2954.058	57.157	4	....
44.163	8r	....	57.484	9r	2957.485	60.764	3	....
44.624	4r	....	65.379	9r	2965.381	62.064	3	....
45.177	5r	....	67.019	10r	2967.016	65.129	3	....
2746.580	4r	....	2970.227	10r	2970.223	3166.551	3	....

Wave-length	I.	Rowland	Wave length	I.	Rowland	Wave-length	I.	Rowland
3171.473	3	....	3397.117	3	....	3609.011	2	3609.015
75.556	7	....	3399.468	7	....	12.242	2	3612.237
78.122	5	....	3402.392	4	....	17.474	1	....
85.015	3	....			3406.602,	17.944	5u	3617.939
88.947	5	....	06.578	2	in Sun	18.918	7r	3618.922
91.778	5	....			3406.572	22.158	5	3622.161
92.921	8	....			3406.965,	30.506	3	....
93.423	8	....	06.938	4	in Sun	31.617	6r	3631.616
3199.638	7	....			3406.943	32.195	5	....
3200.595	7	....	13.275	5	....	40.541	5	3640.545
05.513	8	....	18.649	5	....	47.997	7r	3647.995
10.953	5	....	24.430	5r	....	50.429	3	....
12.112	8	....			3427.282,	51.615	5	....
14.158	10	3214.152	27.263	5	in Sun	55.625	3	....
16.057	5	....			3427.263	59.673	5	....
22.187	10r	3222.197	40.762	9r	3440.756	69.674	5	....
25.905	10r	3225.907	41.138	8r	3440.135	76.461	3	....
28.379	3	....	44.025	7r	3444.024	80.062	4r	3680.064
31.091	8	....	45.301	5	....	83.205	3	3683.209
39.564	8	....	50.484	4	....	87.609	4r	3687.609
44.308	5	....	58.454	3	....	3695.202	3	3695.208
46.617	3	....	60.067	4	....	3702.180	2	....
48.332	5	....	66.006	5r	3466.010	05.714	4r	3705.715
53.043	3	....	71.413	3	....	07.199	3	3707.201
57.724	3	....	71.497	3	....	09.395	5r	3709.395
65.746	8	....	75.600	6r	3475.602	20.083	10r	3720.082
71.129	5	....	76.850	6r	3476.848	22.710	6r	3722.712
80.386	5	....	83.159	3	....	24.527	5	....
84.720	3	....	85.490	3	....	27.769	5r	3727.768
86.884	7	....	90.721	6r	3490.724	31.102	2	....
92.721	5	....	3497.989	5r	3497.991	32.541	5	3732.549
3298.263	5	....	3500.716	3	....	33.470	5r	3733.467
3306.106	7	3306.119	06.650	3	....	35.016	9r	3735.012
06.479	7	3306.481	08.627	2	....	37.278	8r	3737.280
14.868	5	....	08.663	2	....	43.510	6r	3743.506
17.251	3	....	13.974	5	3513.981	45.710	7r	3745.708
25.589	3	....	21.415	5r	3521.409	48.409	7r	3748.410
28.992	5	....	26.196	4r	....	49.634	8r	3749.633
37.793	4	....	26.822	4	....	58.381	8r	3758.380
42.034	3	....	29.960	3	....	63.940	8r	3763.939
42.340	4	....	36.694	4	....	67.339	7r	3767.342
48.056	4	....	40.287	2	....	70.452	2	....
51.882	3	....	45.793	4	....	76.606	3	....
55.355	4	....	53.898	3	....	78.670	2	....
66.917	3	....	58.672	5r	3558.674	88.031	5	3788.029
66.993	3	....	65.535	8r	3565.530	90.242	5	....
67.675	5	....	70.257	8r	3570.253	95.149	8r	3795.148
78.814	5r	....	81.348	7r	3581.344	98.658	6r	....
80.242	4	....	85.478	4r	....	3799.694	6r	....
84.113	4	....	87.137	4r	....	3801.822	3	....
		3389.913,	94.767	4u	....	06.847	3	....
89.882	2	in Sun	3599.781	2	....	13.202	5	....
		3389.884	3605.619	4	3605.621	15.987	8r	3815.984
3394.721	3	....	3606.836	4	3606.836	20.573	9r	3820.566

Wave-length	I.	Rowland	Wave-length	I.	Rowland	Wave-length	I.	Rowland
3824.591	6r	....	4007.429	3	....	4247.604	5	....
26.028	8r	3826.024	17.303	2	....	50.299	8	4250.300
27.967	7r	3827.973	22.029	5	....	50.948	8	4250.949
33.463	3	....	30.670	3	....	60.656	9	4260.647
34.370	8r	....	32.796	2	....	71.333	7	....
40.586	7r	3840.589	44.776	2	....			4271.920,
41.194	8r	....	45.978	10r	4045.975	71.933	10r	in Sun
50.114	8r	....	55.706	3	....			4271.934
56.515	6r	....	62.605	5	....	82.567	7	....
60.054	10r	3860.050	63.755	10r	4063.755	85.614	4	....
65.670	6r	....	68.138	5	....	91.631	3	....
72.640	6r	....	71.901	8r	4071.903	94.290	6r	....
78.166	6r	....	79.999	3	....	4299.420	6r	....
78.722	4	....	84.666	5	....	4309.542	4	....
86.426	6r	3886.421	96.135	5	....	15.255	6	....
87.193	5r	....	4098.346	5	....			4325.932,
93.538	3	....	4107.646	5	....	25.941	8	in Sun
95.801	5r	....	14.608	4	....			4325.939
3899.853	5r	....	18.709	8	....	37.219	6	....
3903.097	6r	....	37.156	6	....	46.739	3	....
06.624	6	....	44.033	10u	....	52.910	5	4352.908
09.980	3	....	54.662	4	....	58.689	3	....
13.784	3	....	71.069	4	....	67.759	5	....
16.880	4r	3916.886	75.799	5	....	69.954	5	4369.948
18.467	3r	....	81.918	5	....	76.104	6	4376.108
20.404	6r	....	87.221	8	....	83.724	8r	4383.721
23.059	3r	....	91.611	8	....	4391.137	4	....
28.073	5r	3928.060	4199.256	6	4199.257	4404.929	8	4404.928
35.966	4	....			4202.187,	15.301	8	4415.298
41.032	4	3941.034	4202.195	8	in Sun	27.490	6	....
45.269	2	....			4202.195	30.801	5	....
48.927	4	....	10.521	5	....	42.522	6	....
56.610	3	....	19.523	5	....	47.907	6	4447.912
56.823	5	....			4222.396,	54.572	4	....
66.219	3	....	22.387	5	in Sun	61.838	5	....
69.411	6r	....			4222.382	66.737	6	....
77.892	6	....	27.606	6	....	69.566	6	....
84.112	4	....	33.771	7	....	76.207	6	....
86.330	4	....	36.118	8	....	84.420	5	....
96.147	3	....	38.980	6	....	89.929	4	....
3998.211	3	....	4245.423	5	....	4494.755	6	4494.756

OBSERVATIONS OF THE BRIGHTNESS OF *NOVA PERSEI.*

By GEORGE C. COMSTOCK and JOEL STEBBINS.

THE following comparisons of the brightness of *Nova Persei* with surrounding stars have been made by the method of Argelander, and in their reduction the magnitudes of the comparison stars have been taken from the column heading "H. P." in Hagen's First Chart and Catalogue for Observing *Nova Persei.* An opera glass has been used in making the larger part of the comparisons, but a few of the earlier ones were made with the naked eye.

Each observer has made his estimates quite independently of the other, but the observations have been continuously compared one with another, so that there has probably been produced in the later observations some tendency toward an artificial agreement in the estimates. Each observer has determined his light scale, value of one grade, from all of his own observations suitable for that purpose, excluding comparison stars where the estimated difference of brightness was less than three grades. We find for C, 1 grade = 0.12 magnitude and for S, 1 grade = 0.10 magnitude. From an examination of the residuals furnished by simultaneous comparisons of the *Nova* with different stars, the probable error of a single comparison is found to be aproximately 0.1 magnitude.

In the following table the *Nova* is represented by the letter *N*, and, save in the case of *Aldebaran*, all comparison stars are to be supposed to have the word "*Persei*" printed after the letter or number by which they are designated. The letters "SS" in the last column indicate that the estimate by S was made, not in grades, but in fractional parts of the total interval between the comparison stars. For example, κ, 1, *N*, 2, σ . . . . SS, means than in respect of brightness *N* was one third of the way from κ to σ. The hour at which the observation was made is expressed in Central Standard time, *i. e.*, six hours slower than Greenwich mean time.

1901	Hour	Comparison	Mag.	Obs.	1901	Hour	Comparison	Mag.	Obs.
Feb. 24	11.0	*N Aldebaran*	1.1	C	April 2	8.0	*N*, 36	5.3	S
26	7.0	*Aldebaran*, 6 *N*	1.8	C	2	8.0	30, 1, *N*	5.5	S
26	7.0	*N*, 3, α	1.5	C	2	8.0	κ, 2, l, 1, *N*	5.6	SS
27	—	*N*, α	1.9	C	3	7.3	30, 2, *N*	5.6	C
27	—	*N*, 3, β	2.0	C	3	9.0	*N*, 36	5.3	S
28	—	*N*, 1, α	1.8	C	3	9.0	30, 1, *N*	5.5	S
Mar. 3	9.0	*N* β	2.4	C	8	9.0	(κ σ) *N*	4.3	C
3	9.0	*N* (α ε)	2.4	C	8	9.0	ν, 2, *N*	4.1	C
4	7.0	β, 2, *N*	2.6	C	9	8.0	*N*, 2, σ	4.3	C
4	7.0	*N*, 4, δ	2.6	C	9	8.0	*N* ψ	4.2	C
6	7.3	δ, 2, *N*	3.3	C	10	8.0	30, 1, *N*	5.5	C
6	7.3	*N*, 4, ν	3.4	C	14	9.0	*N*, 36	5.3	S
11	6.7	*N*, κ	4.1	C	14	9.0	30, 1, *N*	5.5	S
15	7.0	κ = *N* = ν	4.0	C	14	9.0	*N*,1,B.D.+45°,811	5.5	S
15	8.7	(ν κ), 1, *N*	4.1	C	14	10.0	30, 2, *N*	5.6	C
16	—	*N*, 2, (ν κ)	3.8	C	14	10.0	*N*, 1, 36	5.2	C
17	—	*N*, 2, (ν κ)	3.8	C	15	8.2	30, 2, *N*	5.6	S
20	9.0	*N*, 3, ν	3.5	C	15	8.2	*N*,1,B.D.+45°,811	5.5	S
20	9.0	*N*, δ	3.1	C	15	8.2	36, 1, *N*	5.4	S
21	8.2	*N*, l	5.1	S	15	8.5	30, 2, *N*	5.6	C
21	9.2	κ, 5, *N*	4.7	C	15	8.5	*N*, 36	5.3	C
21	9.2	*N*, 2, σ	4.3	C	18	9.0	ν, 1, *N*, 2, l	4.3	SS
21	9.2	*N*, 2, l	4.5	C	19	8.8	*N*, (36, 30)	5.4	S
22	7.2	*N*, 1, σ	4.4	C	20	8.7	36, 1, *N*	5.4	C
22	7.2	*N*, 3, l	4.7	C	20	8.7	30, 2, *N*	5.6	C
22	7.5	*N*, σ	4.5	S	20	—	36, 1, *N*	5.4	S
22	7.5	*N*, (κ l)	4.6	S	20	—	*N*,1,B.D.+45°,811	5.5	S
22	9.0	*N*, (ν l)	4.5	S	20	—	30, 3, *N*	5.7	S
22	9.0	κ, 1, *N*, 2 σ	4.2	SS	22	10.0	*N* (ν l)*	4.5	S
22	9.0	*N*, 1, ι	4.1	S	23	8.2	κ, 2, *N**	4.3	C
22	9.2	κ, 2, *N*	4.3	C	23	8.2	*N*, 1, ψ*	4.1	C
27	7.3	*N*, ξ	4.1	S	23	9.0	ν, 2, *N**	4.1	S
27	7.3	*N*, ι	4.2	S	24	8.2	*N*, 30	5.4	C
27	7.3	(ν κ), 1, *N*, 4, σ	4.1	SS	24	8.2	36, 2, *N*	5.5	C
27	8.5	*N*, 1, σ	4.4	C	24	8.5	*N*,1,B.D.+45°,811	5.5	S
27	8.5	ν, 5, *N*	4.5	C	24	8.5	36, 1, *N*	5.4	S
27	8.5	*N*, 2, l	4.9	C	24	8.5	30, 2, *N*	5.6	S
28	7.2	σ, 1, *N*	4.6	S	25	8.0	30, 1, *N*	5.5	C
28	7.2	ν, 1, *N*, 2, l	4.7	SS	25	8.0	36, 2, *N*	5.5	C
28	7.2	*N*, 1, l, 1, 30	4.8	SS	25	9.8	*N*,1,B.D.+45°,811	5.5	S
31	8.0	κ, 4, *N*	4.6	C	25	9.8	36, 1, *N*	5.4	S
31	8.0	*N*, 2, σ	4.3	C	25	9.8	30, 2, *N*	5.6	S
31	8.0	ν, 3, *N*	4.3	C	26	8.0	30, 2, *N*	5.6	C
31	8.0	*N*, 2, ω	4.7	C	26	8.0	36, 3, *N*	5.7	C
31	8.0	(ν κ), 1, *N*	4.1	S	26	8.0	*N*, B.D.+45°, 811	5.6	S
31	8.0	*N*, ι	4.2	S	26	8.0	36, 2, *N*	5.5	S
31	8.0	*N* ξ	4.1	S	26	8.0	30, 3, *N*	5.7	S
31	8.0	*N*, (ν σ)	4.2	S	May 1	8.5	l, 2, *N*	5.3	S
April 2	7.8	l, 2, *N*	5.3	C	1	8.5	*N*, 2, 36	5.1	S
2	7.8	*N*, 1, 30	5.3	C	12	10.0	*N* (l, 36)*	5.2	S
2	7.8	36, 1, *N*	5.4	C					

* Through clouds.

WASHBURN OBSERVATORY,
Madison, May 1901.

ON THE DENSITY OF THE SOLAR NEBULA.

By Anne Sewell Young.

It would not seem unreasonable to suppose that a possible law of density of the original solar nebula might be determined from considerations based upon the distribution of the moment of momentum of the solar system.[1]

In this paper I will outline the method by which a law of density has been determined for a nebula such that the distribution of its moment of momentum is not inconsistent with that of the solar system. The test of the correctness of this law, or rather of the hypotheses upon which it depends, will be the comparison between the distribution of mass in the supposed nebula and in the present system. The results may have some bearing upon the nebular hypothesis, inasmuch as the assumptions made do not differ widely from those made in regard to the development of the solar nebula.

Briefly stated, this was the method of procedure. It was assumed that the original solar nebula was spherical in form, extending at least to the limits of the orbit of the planet *Neptune*; also that its mass, if not homogeneous, was arranged in homogeneous concentric layers such that the law of its density might be expressed as the sum of a series of $i+1$ terms of the form $\frac{a_i}{r^i}$, in which the a_i are constants to be determined from the investigation, and r is the distance from the center of the nebula. This expression for density was substituted in the integral for the moment of momentum of a sphere, which could then be integrated, its value being expressed in terms of a_i and r. Values of r corresponding to the mean distances of the various planets were substituted in this expression; the results were placed equal

[1] For this suggestion I am indebted to Dr. F. R. Moulton, of The University of Chicago.

to the numerical values of the moment of momentum of respective systems consisting of the Sun and the planets, exclusive of those whose orbits lie beyond the orbit of the one whose distance from the Sun was used as the value of r. This gave a set of equations which would of necessity be simultaneous if the conditions upon which they were based were actual, and whose unknowns were the constants, a_i, of the assumed law of density.

It was also assumed that the planets were formed from the outer limits of the nebula in the order of their distances from the Sun; that when the nebula extended to the limits of the orbit of any planet, the angular rotational velocity of the entire mass was the same as the present angular velocity of the planet; and that the moment of momentum of the system has been constant. This last assumption must be true unless the system has been acted upon by some external force since the time under consideration.

It will be shown first that the nebula could not have been homogeneous.

Let $I\omega$ represent the moment of momentum of a sphere of radius r, rotating with the angular velocity ω, and let σ represent the density of the sphere. Then

$$I\omega = \omega \int_0^\pi \int_0^{2\pi} \int_0^r \sigma r^4 \sin^3 \phi \, d\phi \, d\theta \, dr \quad . \ (a) \ .$$

If σ is a constant (the condition for homogeneity),

$$I\omega = \frac{8}{15} \pi \sigma r^5 \omega = \frac{2}{5} M r^2 \omega \ ,$$

where M is the whole mass of the system. If we neglect the diminution of mass of the original nebula and the consequent loss of moment of momentum due to the abandonment of the planets in succession, $r^2\omega$ should be a constant. The logarithmic values for this product, computed for the mean distance of each planet from the Sun in terms of the Earth's distance, are as follows:

Neptune	0.732561	*Jupiter*	0.350505	*Venus*	9.922976
Uranus	0.635268	*Mars*	0.084746	*Mercury*	9.787242
Saturn	0.482886	Earth	9.993712	Sun	5.755774

A certain part of this variation could be accounted for by the separation of the planets from the parent mass. The masses of the planets are small as compared with the entire mass, hence the mass factor would change but little. That the variations in the values of $r^2\omega$ are entirely out of proportion to the loss of moment of momentum occasioned in this way will be made evident by reference to the table of orbital momenta given later. It will be seen that a very great change would be expected between the orbits of *Saturn* and *Mars*, because of the great orbital momentum of *Jupiter*, but that only small changes should take place between *Mars* and the Sun. We find, however, that $r^2\omega$ was reduced to about *two-fifths* of its former value in the first case, and to less than *one ten-thousandth* in the latter. It is, therefore, evident that the nebula could not have been homogeneous.

Let us now consider the assumption that the mass was arranged in homogeneous concentric layers, the density being a function of the radius. Let us suppose that the density may be represented by a series of the form

$$\frac{a_0}{r^0}+\frac{a_1}{r}+\frac{a_2}{r^2}+\frac{a_3}{r^3}+\ldots\ldots,$$

in which r represents the distance from the center to any given point, and a_0, a_1, a_2, etc., are constants to be determined. Any one of them may equal unity or reduce to zero. In order to avoid the difficulties arising from terms which become infinite in the expression for the moment of momentum, I limited the series to five terms. Substituting in (a) the value of σ, which was, therefore,

$$a_0+\frac{a_1}{r}+\frac{a_2}{r^2}+\frac{a_3}{r^3}+\frac{a_4}{r^4},$$

we obtain

$$I\omega=\frac{8\pi}{3}\left[\frac{1}{5}a_0r^5+\frac{1}{4}a_1r^4+\frac{1}{3}a_2r^3+\frac{1}{2}a_3r^2+a_4r\right]\omega\,.$$

In the formation of the equations, the following data were used, the unit of time being the mean solar day, the unit of distance the mean distance of the Earth from the Sun:

	Sid. Period[1]	Mean Distance[2]	Orbital Momentum[2]
Neptune	60193.2^d	30.05660	1.806
Uranus	30681	19.18239	1.323
Saturn	10774.9	9.538786	5.456
Jupiter	4346.5	5.202776	13.469
Mars	687	1.523692	0.00253
Earth	365.25	1.000000	0.01720
Venus	224.7	0.723332	0.01309
Mercury	88	0.387098	0.00079
Sun	25.35	0.004664	0.444

Darwin has shown that the rotational moments of the planets are insignificant in comparison with their orbital moments,[3] and I have therefore disregarded them entirely. The maximum rotational moment is that of the planet *Jupiter*, and is only about $\frac{1}{8000}$ of the orbital moment of momentum of that planet.

The second members of the equations were determined by considering the original total momentum as unity, and deducting for each successive equation that fraction of the whole represented by the orbital momentum of the planet supposed to have been abandoned; that is, the second member would be unity in the equation whose r was the radius of *Neptune's* orbit; in the equation for *Uranus*, the second member would be one diminished by the fraction representing the orbital momentum of *Neptune*, etc.

In this way the following set of equations was formed:[4]

$$(1)\left\{\begin{array}{llll} 29341.620a_0 & +\ 1220.2680a_1 & +\ 54.13189a_2 & \\ +\ 2.701498a_3 & +\ 0.1797608a_4 & =\ 0.1193663 & . \end{array}\right.$$

$$(2)\left\{\begin{array}{llll} 6095.019a_0 & +\ 397.1767a_1 & +\ 27.60704a_2 & \\ +\ 2.158780a_3 & +\ 0.2250794a_4 & =\ 0.1097987 & . \end{array}\right.$$

$$(3)\left\{\begin{array}{llll} 527.69680a_0 & +\ 69.15147a_1 & +\ 9.666016a_2 & \\ +\ 1.520006a_3 & +\ 0.318700a_4 & =\ 0.1027897 & . \end{array}\right.$$

$$(4)\left\{\begin{array}{llll} 63.14962a_0 & +\ 15.17210a_1 & +\ 3.888206a_2 & \\ +\ 1.121000a_3 & +\ 0.4309237a_4 & =\ 0.0738853 & . \end{array}\right.$$

[1] C. A. YOUNG, *General Astronomy*, Art. 489.

[2] G. H. DARWIN, *Philosophical Transactions of the Royal Society*, Part II, 1881, pp. 516, 517.

[3] *Ibid.*, p. 523.

[4] In these equations both members have been divided by $\frac{8\pi}{3}$.

$$(5)\left\{\begin{array}{l} 0.8607198a_0 + 0.7061136a_1 + 0.6178970a_2 \\ + 0.6082893a_3 + 0.7984413a_4 = 0.0025303 \end{array}\right. .$$

$$(6)\left\{\begin{array}{l} 0.1971253a_0 + 0.2464056a_1 + 0.3285420a_2 \\ + 0.4928132a_3 + 0.9847189a_4 = 0.0025168 \end{array}\right. .$$

$$(7)\left\{\begin{array}{l} 0.0634480a_0 + 0.1096454a_1 + 0.2021116a_2 \\ + 0.4191262a_3 + 1.1588760a_4 = 0.0024257 \end{array}\right. .$$

$$(8)\left\{\begin{array}{l} 0.0071114a_0 + 0.0229638a_1 + 0.0790973a_2 \\ + 0.3065009a_3 + 1.5835830a_4 = 0.0023564 \end{array}\right. .$$

$$(9)\left\{\begin{array}{l} 0.0000000a_0 + 0.00000002a_1 + 0.00000048a_2 \\ + 0.00015444a_3 + 0.0662310a_4 = 0.0023522 \end{array}\right. .$$

I first attempted to effect a solution by using the four equations derived by combining (1) and (2), (3) and (4), etc., together with the solar equation. The values of a_0, a_1, a_2, etc., determined in this way failed to satisfy any of the original equations of the planets, a large negative residual in equation (1) being balanced by an equal positive residual in equation (2); the same result was found for the other three pairs.

It could hardly be expected that the solar equation would be found consistent with the others, as the present condition of the Sun must be entirely unlike what it was when it extended even to the limits of *Mercury's* orbit. It was decided, therefore, to confine the solution to the first five equations, formed from the five planets which lie beyond the orbit of the Earth. There is no evident reason why the distribution of mass should change radically between the limits of the orbits of *Mars* and *Neptune*, and, because of the rarity of the gases and the slow rotation of the entire mass, the assumption of sphericity of form would not be a violent one. The results obtained gave the following expression for the density of the solar nebula:

$$\sigma = 0.00000767 - \frac{0.00019634}{r} - \frac{0.0025714}{r^2} + \frac{0.10607164}{r^3} - \frac{0.0754859}{r^4}$$

These values of a_0, a_1, a_2, etc., satisfied the five equations in every case to the sixth decimal place, and in all but one to the seventh; but they failed entirely to satisfy the conditions expressed by the equations for the Earth, *Venus*, *Mercury* and Sun.

Having found a law of density consistent with the moment of momentum of the superior planets, the next step was the

computation of the amount of material within a spherical shell contained between the limits of the orbits of *Mars* and *Saturn*. This mass should be at least equal to the mass of the planet *Jupiter*, as it is altogether improbable that the nebula should have expanded instead of contracted during the process of development. This was done by computing the value of the integral

$$M = 4\pi \int_{r\,(Mars)}^{r\,(Saturn)} \left(a_0 + \frac{a_1}{r} + \frac{a_2}{r^2} + \frac{a_3}{r^3} + \frac{a_4}{r^4}\right) r^2 dr \ .$$

It was found that the entire mass lying between these limits would be only about *one fifth* of the Earth's mass, whereas the mass of *Jupiter* is more than *three hundred* times that of the Earth. These results show that the assumed law of density is an impossible one, and yet the method of attack seems legitimate. Because of the great discrepancies in the figures, it would seem that the law of density cannot be represented by a series of this general type such that the distribution of both the moment of momentum and the mass of the nebula will be satisfied. While one should not attach great importance to conclusions based upon such a large number of assumptions, several of which may be incorrect, from the preceding discussion it seems probable that the density of the solar nebula was irregular.

I may add that in an earlier attempt to find an expression for density which should be consistent with all nine equations, I assumed the form

$$\sigma = \frac{a_0}{(1+r)^0} + \frac{a_1}{1+r} + \frac{a_2}{(1+r)^2} + \frac{a_3}{(1+r)^3} + \ldots\ldots ,$$

using nine terms of the series. This particular form removes all difficulty arising from terms which become infinity in the expression for the moment of momentum when r is zero. The equations were formed and solved, but I do not consider the results of much value, because, as has been suggested, the solar equation probably could not be consistent with the others. The mass tests in this case also show that, with such a distribution of mass, the formation of a planet like *Jupiter* would have been impossible.

Mt. Holyoke College,
March 1901.

Reviews

Ueber die Ursache der Nordlichter. SVANTE ARRHENIUS. *Öfversigt af Konigl. Vetanskaps-Akademiens Förhandlingar, 1900.* Pp. 545–580. Reprinted in the *Physikalische Zeitschrift,* Nov. 10 and 17, 1900.

THE manner in which two domains of science, apparently unrelated, are sometimes united and simplified by a keen observation is beautifully illustrated in the paper whose title has just been given. The brilliant Swedish chemist, S. Arrhenius, here applies Maxwell's electromagnetic theory to the explanation of solar repulsion on comets and to the explanation of the Aurora Borealis. Following is an abstract of the highly plausible result which he obtains:

Solar repulsion of the tails of comets, and the apparent ejection of matter from the Sun to form the corona and solar projections, have long puzzled scientists as seeming exceptions to the law of gravitation. Many theories in explanation of these phenomena have been proposed, electrical repulsion being perhaps the one most generally given.

Kepler[1] attempted the first explanation, basing his hypothesis on the emission theory of light, supposing that the matter might be repelled by the impact of the corpuscles. Newton accounted for the phenomena by supposing such a difference in the density of the surrounding medium as causes the ascension of hot air and smoke.

Euler[2] in the 18th century held that light waves, which he supposed to consist of longitudinal vibrations in the ether, were competent to produce repulsion. This view was so severely criticised that it was soon abandoned. Nevertheless, if Maxwell's electro-magnetic theory of light be accepted, it appears that Euler was, in the main, right. Maxwell[3] proves that in a medium in which electro-magnetic or light waves are propagated, a pressure is produced in the direction of propagation which, at any point, is numerically equal to the total energy per unit volume.

[1] KEPLER, *Principia Mathematica,* I, III, Prop. 41.

[2] EULER, *Mémoires de l'Academie de Berlin,* 1746, 2, 121, 135.

[3] MAXWELL, *Electricity and Magnetism,* 1873. Art. 792.

The amount of solar energy per square centimeter per second at the distance of the Earth is about 0.0417 calories; or 1775 ($42600 \times .0417 = 1775$) gram-centimeters per second per square centimeter. Since the velocity of the Sun's radiations is about 3×10^{10} centimeters per second, the amount of solar energy per cubic centimeter $= 1775 \div 3 \times 10^{10} = 592 \times 10^{-10}$ gram-centimeters. This pressure acts only on the side of bodies toward the Sun, hence bodies are urged away from the Sun in the direction of the beam of light. Though the repulsion produced by the Sun's rays in the vicinity of the Earth is too small to be detected, near the Sun it is vastly greater. The average distance of the Earth from the Sun is about 215.7 times the Sun's radius; at the surface of the Sun the repulsion will then be $(215.7)^2 \times 592 \times 10^{-10} = 2.75 \times 10^{-3}$ grams per square centimeter. The weight of a body at the Sun is 27.47 times that at the Earth. Then a cubical body, 1 centimeter on an edge, of unit density, suspended so that its lower surface were perpendicular to the Sun's rays, would lose about one ten-thousandth part of its weight. If the body were more or less transparent, a deduction would have to be made for the light transmitted; but if the body were a perfect reflector the effect would be doubled, so perhaps computations based on the assumption that all the radiations are absorbed will be near the truth.

If now a cube of the same density 10^{-4} centimeters in diameter were taken, its weight would be 10^{-12} and its area 10^{-8} times that of the first; such a body would lose all its weight when subjected to the Sun's radiations. According to Bredichin[4] the matter composing the tails of comets is, at perihelion, repelled from the Sun with a force 1.5 to 18.5 times its weight. Assuming that the tails of comets are composed of gaseous hydrocarbons whose density could hardly exceed 0.8, the computed diameter of the particles to be thus repelled would lie between 0.1μ and 1.25μ. Such particles would be much larger than simple molecules. Micro-organisms of a diameter not greater than 0.3μ have been observed. When it is considered that these organisms are composed of many complicated organic molecules, it is evident that inorganic particles may be vastly smaller. Indeed liquid films have been produced as thin as $5\mu\mu$ (0.005μ). Particles of this diameter would be 20 times smaller than is necessary to account for the maximum observed cometary repulsion.

[4] BREDICHIN, *Revision des valeurs numeriques de la force répulsive.* Leipsic, Voss, 1885.

As a comet approaches the Sun there is developed on the side toward the Sun an extension of the coma. This is accounted for by supposing that the head of the comet is composed of solid or liquid hydrocarbons of relatively high boiling point, which are vaporized under the intense heat of the Sun; while the particles are comparatively large they fall toward the Sun, but with their further dissipation they will be repelled and form a part of the tail. If the nucleus is heterogeneous, particles of many sizes may be formed, which, by their varying degrees of repulsion, may give rise to several distinct tails, as in the comet of 1744.

The apparent force of repulsion of the tail is not always proportional to the inverse square of its distance from the Sun. This is easily accounted for on the supposition that the size of the particles, and hence their force of repulsion, varies with the distance. It has been observed that comets are more numerous and brighter in years when Sun-spots are plentiful. Measurements made by Savélieff[1] in the summers of 1890, 1891, and 1892 when the number of Sun-spots were in the ratios of 7, 47, and 86, gave for the solar energy values of 29.8, 34.2, and 36 calories per square centimeter per hour. Thus Sun-spots accompany intense solar radiation; this means increased repulsion and the carrying away of a large amount of "cosmic dust," into colder space where the particles may aggregate till they again fall toward the Sun in the form of comets.

A particle having half the critical diameter, and projected from the surface of the Sun, would, in traveling a distance equal to the Sun's radius, acquire a velocity of 430 km per second. Such a particle would traverse a distance equal to the Sun's diameter in less than an hour. A particle with $\frac{1}{18}$ the critical diameter would travel that distance in four minutes. This "cosmic dust" thus shot off from the Sun may account for many of the phenomena of the solar corona, and the zodiacal light.

That these particles thus ejected from the Sun would be strongly electrified is almost certain, when we consider the violent electrical disturbances which always accompany volcanic eruptions. Cathode and Roentgen rays would be developed if the electrification were sufficiently intense, by which the surrounding gases would be ionized. The negative ions, as has been shown by Wilson,[2] would form centers

[1] SAVÉLIEFF, *Comptes Rendus*, **118**, 62, 1894.

[2] WILSON, *Phil. Mag.*, **193**, 289–308, 1899.

of condensation for the "cosmic dust" and consequently the particles finally leaving the neighborhood of the Sun, would be negatively charged, while the positive ions would remain behind. The side of the Earth turned toward the Sun would receive a constant stream of these negatively charged particles, which would, for the most part, remain in the upper strata of the air. Particles of a diameter of 1μ would probably remain as high as 200 km. The atmosphere would be most strongly charged in the direct line between the Earth and the Sun, and in this region cathode rays might be developed. Under the action of the ultra-violet light, which would render the air conducting, the charges would be gradually conducted toward the less illuminated regions to the north and south. The normal circulation of the air would also work toward the same end.

Dr. Paulsen[1] found such a remarkable agreement in essential characteristics between the Aurora Borealis and the cathode rays that he declared the first to be a special form of the second. The great obstacle to the acceptance of his conclusions has been the difficulty of imagining any way in which the cathode rays could be produced; a difficulty which the present theory aims to overcome.

Since cathode rays tend to follow the lines of force in a magnetic field, the rays will, near the equator, where the lines of force are parallel to the Earth's surface, remain in the upper air, never penetrating deep enough to produce any visible illumination. Still aurora lines are found even in equatorial regions in the diffused light after sunset. The nearer the poles the greater the angle which the lines of force make with the Earth's surface, and the deeper the cathode rays will penetrate, till they reach strata sufficiently dense to produce a very considerable illumination, thus causing the aurora.

Practically all the known facts concerning the aurora harmonize with the theory that the light is produced by cathode rays which arise from negatively electrified particles repelled from the Sun. The remarkable identity of the 11-year periods of the aurora and Sun-spots; the annual, monthly, and daily variations in the number and intensity of the aurora following closely the variations in the position of the Sun and the intensity of its light may all be much more satisfactorily explained by this theory than perhaps by any other.

A. W. AUGUR.

[1] PAULSEN, "Sur la nature et l'origine de l'aurore boreale." *Bull. d. l'Ac. Roy. d. Sc. de Copenhague*, 1894.

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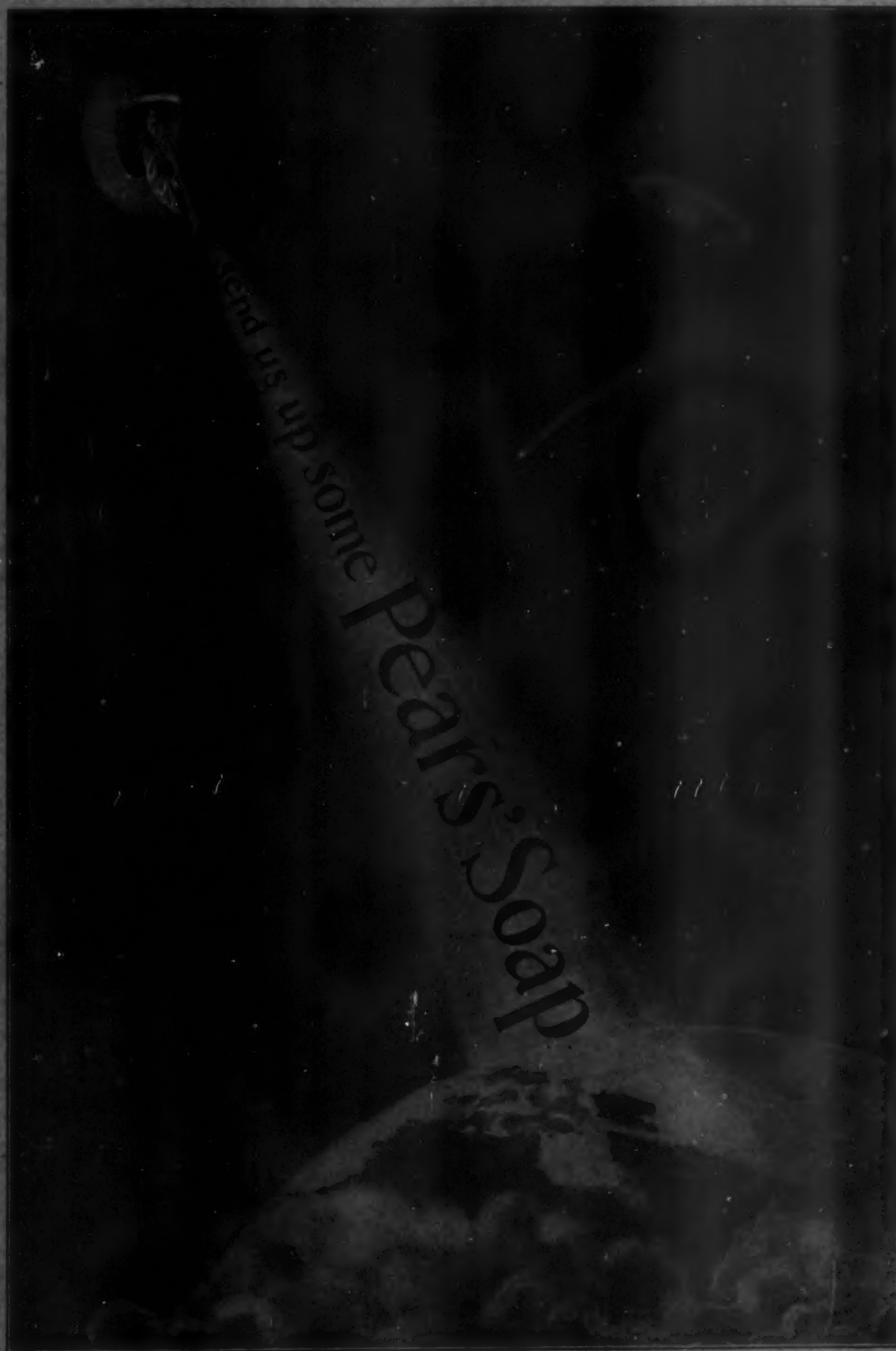

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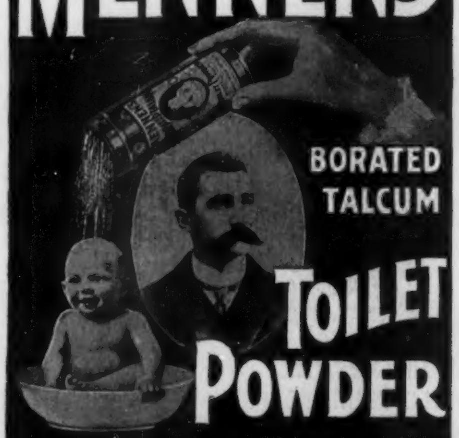

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We are now ready to supply our **Double-Anastigmat Lenses** fitted to the Nos. 2 and 3 **Folding Pocket Kodak**, and the Nos. 3, 4, and 5 **Folding Cartridge Kodak.**

No. 3 Folding Pocket Kodak with Goerz Double-Anastigmat and New Automatic TIB Shutter, complete, $61.50. If you have a Kodak we will fit a Lens for $14.00 less. This Lens and Shutter may be detached for use on other cameras.

For prices, circulars, etc., apply to your dealer, or to the

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